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# THE JAPANESE ALUMINUM INDUSTRY

BY

GLENN L. ALLEN AND VIRGIL MILLER

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## UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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# THE JAPANESE ALUMINUM INDUSTRY[1]

By Glenn L. Allen[2] and Virgil Miller[2]

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[1] Work on manuscript completed April 20, 1948. The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7496."

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## INTRODUCTION

The purpose of this report is to present a comprehensive review of the technology of alumina and aluminum production in the former Japanese Empire, which consisted of the Japanese Home Islands and her dependencies, Formosa, Manchuria, and Korea. Pertinent background material and statistics are given when deemed necessary to make the report self-contained and to make clear the factors underlying Japan's tremendous accomplishments in the production of aluminum.

Japan imported her entire requirements of aluminum, less than 12,000 metric tons annually, before 1933.3/ In that year the industrial production

---

3/ Annual tonnages are for Japanese fiscal year, April 1 to March 31.

in the Home Islands began on a small scale, followed a few years later by small productions in Formosa, Manchuria, and Korea. The aluminum metal produced by these dependencies was fabricated and consumed in the Japanese Home Islands. By 1938, aluminum production had increased to 20,000 metric tons, which satisfied the requirements of the Home Islands. In 1940, Japan canceled her trade agreements with the United States. At that time she had seven plants in operation and produced 30,600 metric tons per year. The peak production for the Japanese Empire was 150,000 metric tons of primary metal in 1943. Production dropped to 118,000 in 1944 and was suspended entirely in August 1945. The production of primary metal in Japan has not been authorized by the Occupational Forces, yet 10,000 tons annually of secondary metal is being recovered from scrap aluminum and various alloys.

Both economic and political factors contributed to Japan's rapid rise, beginning in 1936, to the fourth-ranking world producer of aluminum. Before 1936, development of the Japanese aluminum industry was retarded by the high cost of electric energy, lack of experience and skill in production methods, and the necessity of importing raw materials. After 1936, power resources were developed to provide low-cost hydroelectric energy. The domestic coal supply was adequate for supplying the 4 tons of coal required per ton of metal produced and for generating standby and primary electric power. She adopted the Bayer process and bauxite as the raw aluminum source instead of alunite, clay, and other aluminous materials. Equipment and operating engineers were obtained from the United States, Germany, Sweden, and Norway. Equipment designs in the Bayer alumina plants are almost identical to those of the United States, and the basic Bayer process and its operation are essentially the same as those in Germany and the United States. The raw-materials situation was as good as that of any other major producer except the United States; land and water transport was well-developed, costs were reasonable, and labor was cheap. Japan has no known deposits of bauxite ore in the Home Islands and depended largely on imports of bauxite from the Bintan Island, near Singapore, Johore, and Palau. Bauxite ores were used for all the alumina produced in Formosa and 90 percent of that produced in the Japanese Home Islands. The remaining 10 percent of Japanese alumina was mostly from aluminous shale imported from Manchuria and northern China. Japan had ample facilities for the production of both soda ash and caustic soda, but the sodium chloride used in their manufacture had to be imported, mostly from Korea and north China. The Hall-Herault electrolytic process was used for the reduction of alumina to aluminum. The Soederberg continuously formed self-baking electrode, as yet little used in the United States, was generally preferred to the solid electrode. Petroleum coke and pitch coke are used in the manufacture of both anode and cathode carbons. These were obtained largely from domestic producers and by import, chiefly from the United States. Domestic coke ovens and gas plants supplied the pitch required as binding material for the carbon electrodes and for the pitch used to produce pitch coke. Her fluorspar deposits were inadequate to supply the industrial needs. Poor-quality fluorspar ores were imported, largely from China, Manchuria, and Korea. These ores were beneficiated by flotation prior to use as a raw material in the manufacture of synthetic cryolite. Fused cryolite is used as the solvent for the alumina in the electrolytic cell. All aluminum production facilities were placed under virtual[4] government control, and the industry assumed great importance in the Japanese war economy. Prices were fixed by law, and raw materials were channeled to the expanding industrial plants.

The fabrication of aluminum and aluminum alloys kept pace with aluminum production. Virtually all the metal was rolled, fabricated, or cast in the Japanese Home Islands with few exceptions, one of which was a rolling mill in Manchuria. During the 5 years preceding Pearl Harbor, 80 percent of production was to supply military requirements; after 1941, 100 percent. Peak capacity for fabrication of metal was reached in 1944. The capacity of 21 companies rolling aluminum and alloys exclusively was 58,570 metric tons annually. These companies, together with 47 others that fabricate aluminum as well as other metals, had a total rated capacity of 208,000 metric tons annually. These plants, after deducting war damage, had a rated annual capacity of 142,500 metric tons.

## ACKNOWLEDGMENTS

The information and data contained in this report were obtained from Aluminum Metallurgy in the Japanese Empire, Report No. 87, Natural Resources Section of General Headquarters, Supreme Commander for Allied Powers (SCAP), prepared by Glenn L. Allen; comprehensive reports prepared by the staffs of the aluminum companies in response to questionnaires (copies of these reports are in the Natural Resources Section Mining and Geology Division's files in Tokyo and also in the U. S. Bureau of Mines Library at College Park, Md.); a chapter on aluminum prepared by A. L. Jenks in Mineral Resources of Japan proper, 1925-1945, Natural Resources Section Report No. 44; innumerable interviews with company officials, Japanese government agencies, Light Metals Council and Light Metals Rollers' Association; reports prepared by other staff sections of General Headquarters, SCAP, particularly by the Economic and Scientific Section and Statistics and Reports Section; inspection trips to most of the plants. The map showing the location of the aluminous ores in East Asia was reproduced by special permission from Photo Industrial Study No. 4, The Aluminum Industry, an excellent classified report assembled by the Office of the Assistant Chief of Air Staff, Intelligence Headquarters, United States Army Air Forces. Standard references available in Japan were consulted. These included Lidell's Handbook of Nonferrous Metallurgy, United States Bureau of Mines' Minerals Yearbook, The Japan Yearbook, The Mineral Industry, and technical journals such as Engineering and Mining Journal, Mining and Metallurgy, and Chemical Engineering. The excellent cooperation of the Japanese engineers and plant managers aided materially in obtaining sufficient data for a complete report.

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[4] The twenty companies that produced virtually all of the aluminum in the Japanese Empire had an aggregate capitalization of 1,320 million yen, against which were 2,623 million yen in bank loans of funds mostly controlled by the government. In 1941, the yen was quoted at 23.4 cents U. S. currency at legal exchange.

## GENERAL

Conditions exist in the Japanese Home Islands, especially the island of Honshu, that are inducive to a large supply of hydroelectric power for the greater part of the year. During the few winter months, the shortage in demand electric energy was met by steam plants burning coal, of which there was an ample supply. The sources of aluminous ores are shown on the map in figure 1. Alumina and aluminum works in Korea, Manchuria, and Formosa are graphically located in figure 2. On the map of the Japanese Home Islands (fig. 3) are shown the locations of the alumina plants as well as the coal fields. The aluminum plants, supplemented by electric-power zonal rates, are shown graphically on the map of the Japanese Home Islands (fig. 4).

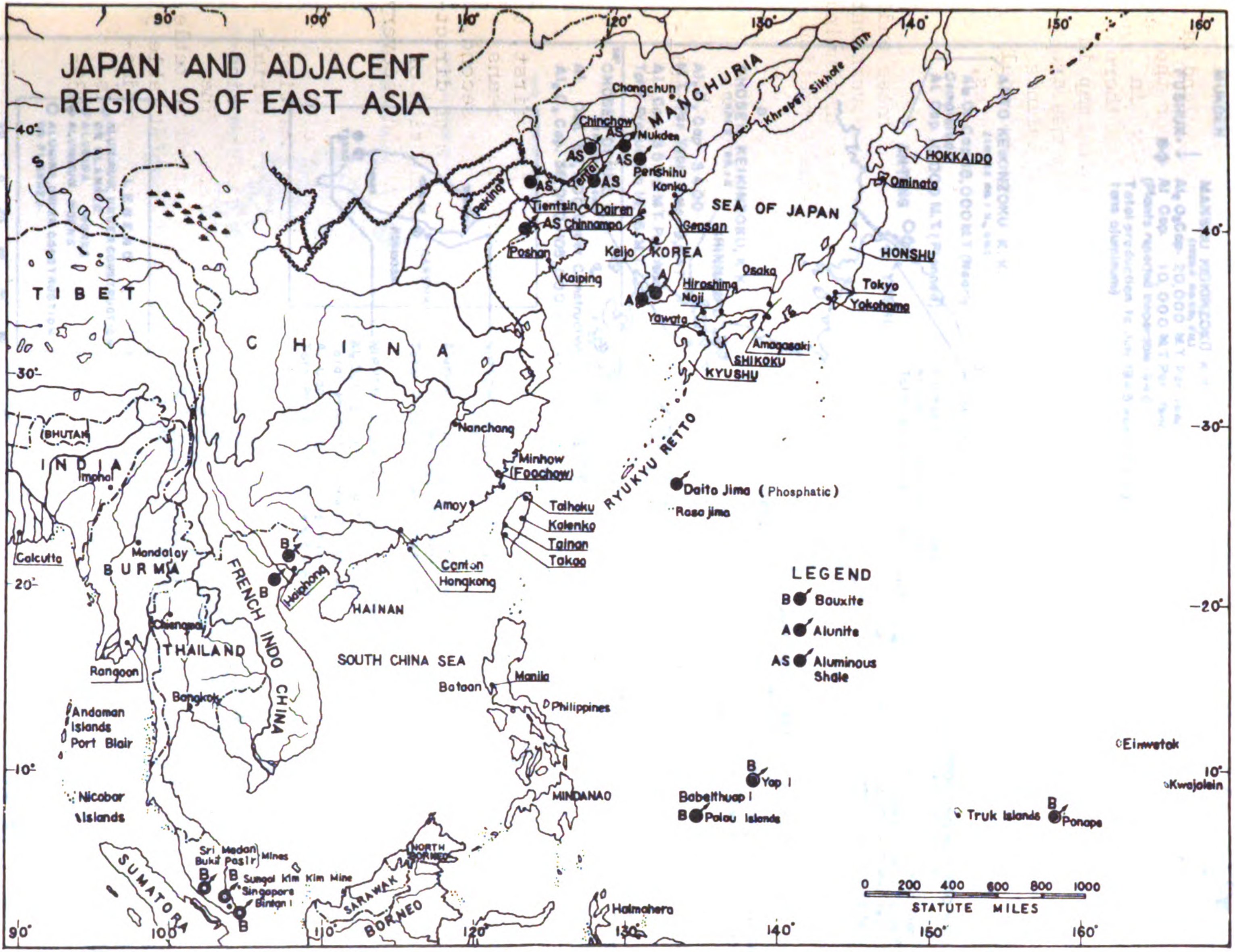
The magazine Modern Metals for April 1948, under the caption Chinese and Reynolds Enter Aluminum Parthership, states: "The Chinese National Government has now approved a contract with Reynolds Metals Company to operate an aluminum industry on a partnership basis***. The contract provides for the formation of the China Aluminum Company.

The China Aluminum Company will take over the alumina plant and the aluminum reduction plants in Taiwan, Formosa, which were acquired by the Chinese Government upon the surrender of Japan. The plants will be rehabilitated and expanded to provide sufficient aluminum for the Chinese market plus exports necessary to obtain dollar exchange."

## ALUMINA PRODUCTION

Modern mass production of aluminum employs two distinct steps - first, a hydrometallurgical process in which alumina is extracted by chemical means from aluminous ore and recovered in the form of nearly pure alumina; second, a pyroelectrometallurgical operation that requires great quantities of direct-current electric energy to reduce the alumina to metal. The production of secondary aluminum amounts to 11 percent of the total production, and recovery details are given under the heading Secondary Aluminum.

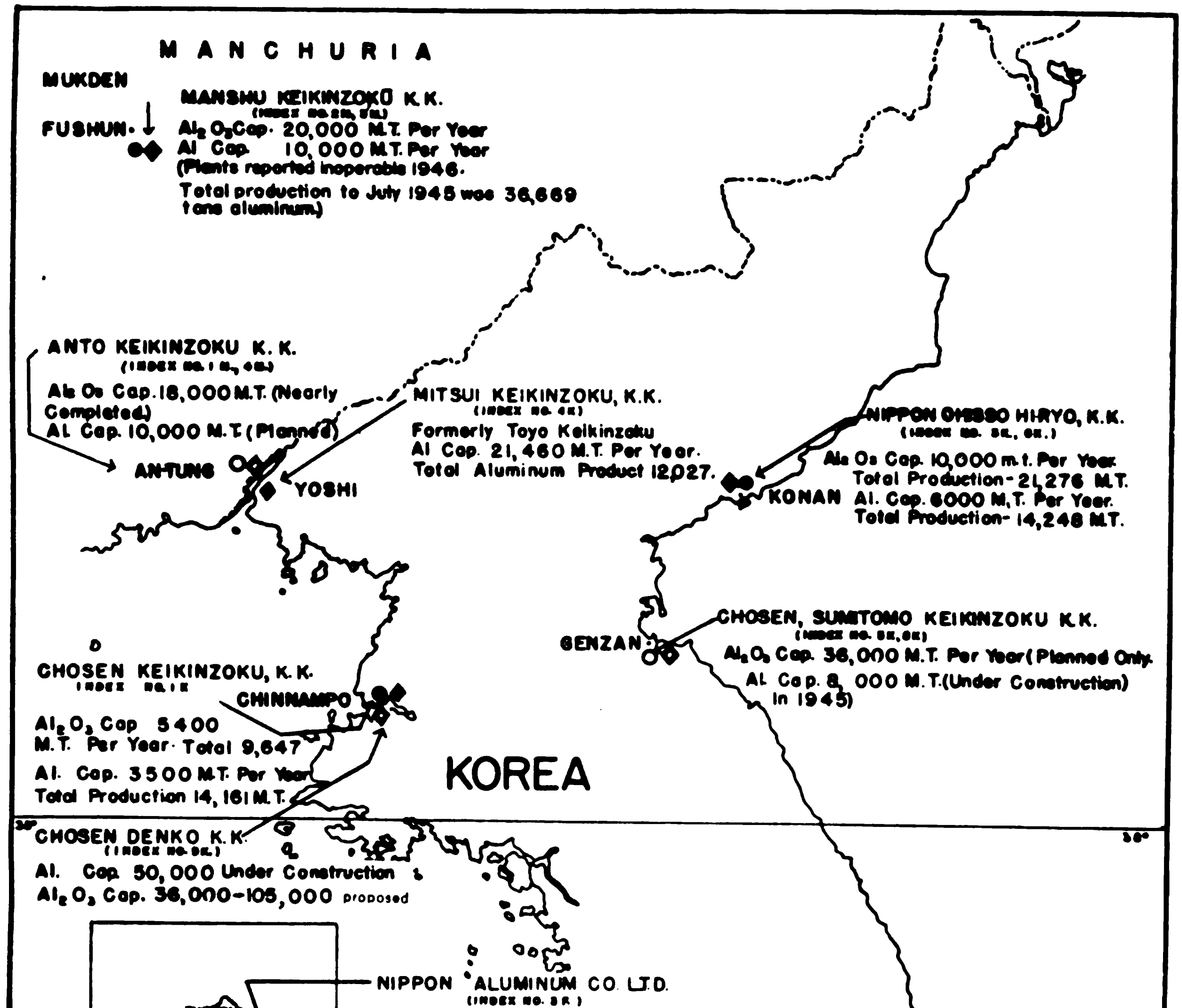
Several workable methods have been developed for the production of alumina. The process used is dependent upon the mineralogical composition of the aluminous ores, which may be bauxite, shale, clay, or other materials containing aluminum. The Japanese metallurgists employed a rather amazing variety of processes in the industrial-scale production of alumina. The Japanese alumina works, together with the processes used, are listed in table 1. Table 2 gives the rated annual capacity for the Home Islands, and table 3 for Korea, Formosa, Manchuria, and North China. The yearly alumina production, by company, in Japan proper (Japanese Home Islands), 1933-1945, is given in table 4; for Formosa, 1937-1945, in table 5; and for Korea, 1939-1945, in table 6.



NATURAL RESOURCES SECTION GHQ SCAP

SOURCE: PHOTO INDUSTRIAL STUDY NO.4 THE ALUMINUM INDUSTRY UNITED STATES FORCES, FEBURARY 1945

Figure I. - Aluminous ore deposits of adjacent regions of East Asia.


M A N C H U R I A
MUKDEN
FUSHUN
MANSHU KEIKINZOKU K.K.
(INDEX NO. 2K, 5K)
Al2 O3 Cap. 20,000 M.T. Per Year
Al Cap. 10,000 M.T. Per Year
(Plants reported inoperable 1946.
Total production to July 1945 was 36,669 tons aluminum.)
ANTO KEIKINZOKU K. K.
(INDEX NO. 1 K, 4K)
Al2 O3 Cap. 18,000 M.T. (Nearly Completed)
AL Cap. 10,000 M.T. (Planned)
AN-TUNG
YOSHI
MITSUI KEIKINZOKU, K.K.
(INDEX NO. 4K)
Formerly Toyo Keikinzoku
Al Cap. 21,460 M.T. Per Year.
Total Aluminum Product 12,027.
NIPPON CHISSO HIRYO, K.K.
(INDEX NO. 5K, 6K.)
Al2 O3 Cap. 10,000 m.t. Per Year
Total Production- 21,276 M.T.
KONAN
Al. Cap. 6000 M.T. Per Year.
Total Production- 14,248 M.T.
CHOSEN, SUMITOMO KEIKINZOKU K.K.
(INDEX NO. 5K, 8K)
GENZAN
Al2O3 Cap. 36,000 M.T. Per Year (Planned Only.
AL Cap. 8,000 M.T. (Under Construction) in 1945)
CHOSEN KEIKINZOKU, K.K.
INDEX NO. 1 K
CHINNAMPO
Al2 O3 Cap 5400 M.T. Per Year. Total 9,647
Al. Cap. 3500 M.T. Per Year
Total Production 14,161 M.T.
KOREA
38°
38°
CHOSEN DENKO K.K.
(INDEX NO. 9K.)
Al. Cap. 50,000 Under Construction &
Al2 O3 Cap. 36,000-105,000 proposed
NIPPON ALUMINUM CO. LTD.
(INDEX NO. 3 F)
Aluminum Cap. 8,000 M.T. Per Year.
(Destroyed By War)
Total Production Was 7195 M.T.
KARENKO
FORMOSA
TAINAN
TAKAO
NIPPON ALUMINUM CO. LTD. (INDEX NO. 1F, 4F)
Al2 O3 Cap. 42,000 M.T. Per Year.
Total Production Was 161,135 M.T.
Al. Cap. 12,000 M.T. Per Year.
Total Production Was 66,566 M.T.
LEGEND
◇ ALUMINUM, UNDER CONSTRUCTION OR PLANNED
● ALUMINA WORKS
◆ ALUMINUM WORKS
○ ALUMINA, UNDER CONSTRUCTION OR PLANNED.
20 0 20 40 60 80

NOTE: Production Totals Are To July 1, 1945.

NATURAL RESOURCES SECTION GHQ SCAP

Figure 2. - Alumina and aluminum works, Korea, Manchuria, and Formosa.

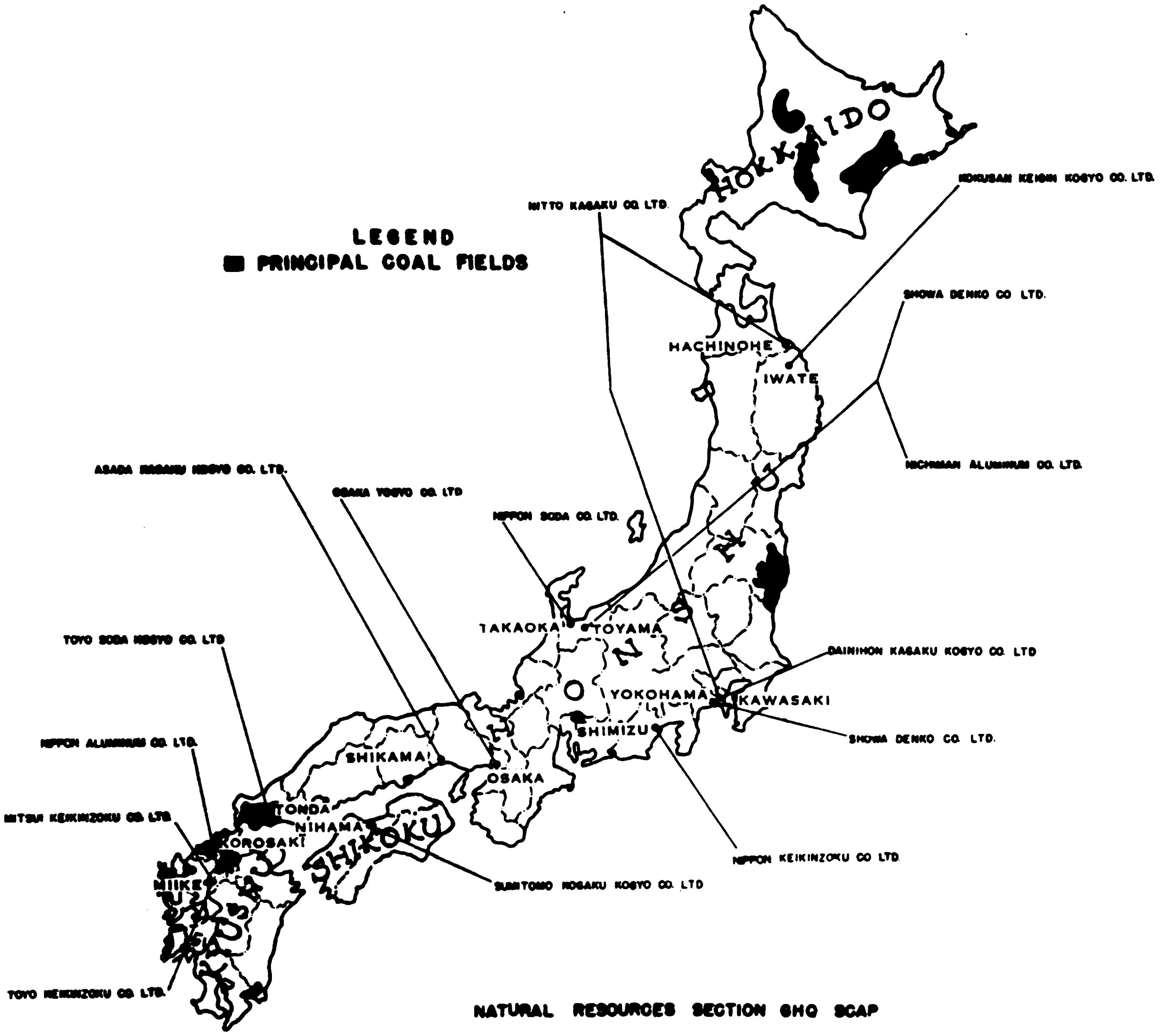
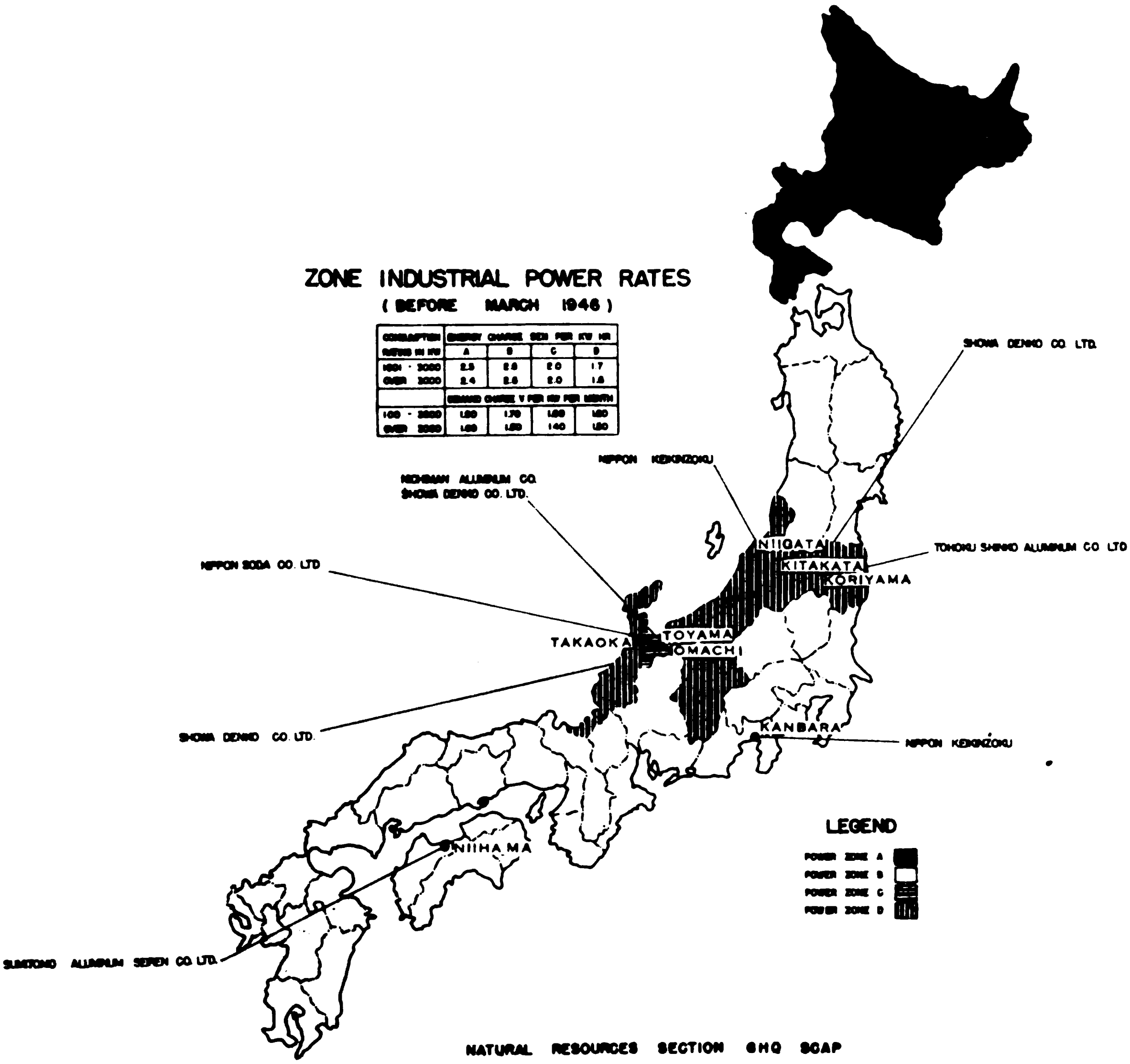


Figure 3. - Alumina plants in the Japanese Home Islands, supplemented by major coal fields.



| CONSUMPTION RATING IN KW | ENERGY CHARGE SEN PER KW HR | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 1001 - 3000 | 2.5 | 2.8 | 2.0 | 1.7 |
| OVER 3000 | 2.4 | 2.6 | 2.0 | 1.6 |
| | DEMAND CHARGE ¥ PER KW PER MONTH | | | |
| 100 - 3000 | 1.80 | 1.70 | 1.60 | 1.50 |
| OVER 3000 | 1.60 | 1.50 | 1.40 | 1.30 |

Figure 4. - Aluminum plants in Japanese Home Islands, supplemented by electric power zonal rates.

TABLE 1. - Alumina processes used in former Japanese Empire

| Plant | Company | Remarks |
|---|---|---|
| 1. Based on use of bauxite and Bayer process: | | |
| Omuta, Japan | Mitsui Keikinzoku | Produced by lime-soda from clinker. |
| Kurosaki, Japan | Nippon Aluminum | Produced by lime-soda from clinker. |
| Shimizu, Japan | Nippon Keikinzoku | |
| Takaoka, Japan | Nippon Soda, KK. | |
| Yokohama, Japan | Showa Denko, KK. | |
| Niihama, Japan | Sumitomo Kagaku, KK. | |
| | Toyo Keikinzoku, KK. | Little-known operation. |
| Takao, Formosa | Nippon Aluminum, KK. | |
| Electric fusion process: | | |
| Toyama, Japan | Showa Denko, KK. | Operated originally on bauxite; changed to aluminous shale. |
| 2. Based on use of aluminous shale and sintering or electric fusion process: | | |
| Toyama, Japan | Showa Denko, KK. | Also operated on bauxites. |
| Chosen, Korea | Chosen Keikinzoku, KK. | |
| Genzan, Korea | Chosen Sumitomo Keikinzoku, KK. | Plant planned only. |
| Lime-soda-sinter process (LSS): | | |
| Tonda, Japan | Toyo Soda, KK. | Produced aluminum tri-hydrate. |
| Omuta, Japan | Mitsui Keikinzoku, KK. | Partially converted to LSS process in 1945. |
| Kurosaki, Japan | Nippon Aluminum, KK. | Partially converted to LSS process in 1945. |
| Konan, Korea | Nippon Chisso, KK. | |
| Autung, Manchuria | Anto Keikinzoku, KK. | Plant nearly completed in 1945. |
| Chanten, N. China | Kakoku Keikinzoku | Plant nearly completed in 1945. |
| Calcium aluminate process: | | |
| Fushun, Manchuria | Manshu Keikinzoku, KK. | |
| Caustic soda process: | | |
| Chosen Denko, Korea | Chosen Denko, KK. | Under construction in 1945. |
| Powdered shale, direct reduction | | |
| 3. Based on use of alunite and caustic soda process: | | |
| Shikama, Japan | Asada Kagaku Kogyo | Small commercial production. |
| Osaka, Japan | Osaka Yogyo Cement, KK. | Small commercial production. |
| Yokohama, Japan | Showa Denko, KK. | Plant later changed to Bayer process Tanaka. |
| Shimizu, Japan | Nippon Keikinzoku, KK. | Plant later changed to Bayer. |
| 4. Based on domestic clay: | | |
| Kawasaki, Japan | Dai Nippon Kagaku | Hydrochloric acid solvent. |
| Iwate, Japan | Kokusan Keigin, KK. | Sulfur dioxide. |
| Niihama, Japan | Sumitomo | Sulfuric acid solvent. |
| 5. Based on aluminum phosphate: | | |
| Hachinohe, Japan | Nitto Kagaku Kogyo | Sulfuric acid solvent small production. |
| 6. Based on other miscellaneous processes: | | |
| Osaka, Japan | Osaka Yogyo Cement, KK. | No data. Reported converted to cement manufacturing in 1938. |

Source: Company reports, Light Metal Control Association, and others.

TABLE 2. - Rated annual capacity, alumina plants, Japan proper

| Company | Plant and location, Shi, Pref. | Annual cap. MT[2] in 45 | Largest production | Year | Remarks |
|---|---|---|---|---|---|
| Asada Kagaku Kogyo, KK. .. | Shikama<br>Shikama, Hyogo | 1,400 | 1,190 | 1939 | NaOH on alunite. |
| Dia Nippon Kagaku, KK..... | Kawasaki<br>Kawasaki, Kanagawa | 12,000 | 64 | 1944 | HCl process on clay. |
| Kokusen Keigin, KK. ...... | Iwate, Kurosawajiri,<br>Iwate | 1,400 | 289 | 1941 | $SO_2$ process on clay. |
| Mitsui Keikinzoku, KK. ... | Omuta<br>Omuta, Fukuoka | 20,000 | 11,178 | 1944 | Bayer process on Palau bauxite.<br>Partly changed to lime-soda-sinter. |
| Nippon Aluminum, KK. ..... | Kurosaki,<br>Yawata, Fukuoka | 24,000 | 21,856 | 1943 | Bayer on Bintan bauxite.<br>Lime-soda-sinter on Al shale. |
| Nippon Keikinzoku, KK. ... | Shimizu[1]<br>Shimizu, Shizuoka | 100,000 | 113,179 | 1943 | Bayer on Bintan bauxite. |
| Nippon Soda, KK. ......... | Takaoka[1] | 24,000 | 22,828 | 1943 | Bayer on Bintan bauxite. |
| Nitto Kagaku Kogyo, KK. .. | Hachinohe<br>Hachinohe, Aomori | 700 | 424 | 1944 | $H_2SO_4$ on Al phosphate. |
| Osaka Yogyo Cement, KK. .. | Osaka | ND | 992 | 1938 | Converted to cement in 1938.<br>NaOH on alunite. |
| Showa Denko, KK. ......... | Yokohama<br>Yokohama, Kanagawa | 70,000 | 57,288 | 1943 | Bayer on Malay bauxite. |
| Showa Denko, KK. ......... | Toyama[1]<br>Toyama, Toyama | 12,000 | 10,573 | 1940 | Electric fusion on Al shale. |
| Sumitomo Kagaku Kogyo, KK. | Niihama[1]<br>Niihama, Ehime | 25,000 | 45,734 |  | Bayer on Bintan bauxite.<br>Orig. cap. 54,000 |
| Toyo Keikinzoku, KK. ..... | Omuta, Kyushu | ND | 13,956 | 1943 | May be forerunner of Omuta plant, Mitsui. |
| Toyo Soda, KK. ........... | Tonda<br>Tonda, Yamaguchi | 10,000 | 1,981 | 1943 | Lime-soda, Al. shale.<br>Capacity figure doubtful. |
| Total Japan proper... |  | 300,500 | 281,588 |  | Largest production was in 1943. |

[1] Alumina plants located at reduction works.
[2] MT = Metric tons.
ND = No data available.

Source: Light Metals Control Association, company reports, and Economic and Scientific Section Report No. 9, The Aluminum Industry of Japan, Part I.

TABLE 3. - Rated annual capacity, alumina plants, Korea, Formosa, Manchuria, and North China

| Company | Plant and location, Shi, Pref. | Annual cap. MT[3] | Largest production | Year | Remarks |
|---|---|---|---|---|---|
| Korea |  | 15,400 | 9,613 |  |  |
| Chosen Keikinzoku, KK. ... | Chosen, Chinnanpo, Korea[1] | 5,400 | 4,622 | 1944 | Electric fusion process on aluminous shale |
| Nippon Chisso Hiryo, KK... | Konan, Konan, Korea[1] | 10,000 | 4,991 | 1944 | Lime-soda-sinter process on aluminous shale. |
| Chosen Sumitomo Keikinzoku, KK. ......... | Genzan, Genzan, Korea | [2](36,000) | None |  | Electric fusion, aluminous shale planned only. |
| Chosen Denko, KK. ........ | Chosen Denko, Chinnanpo, Korea | [2](105,000) | None |  | Concentrated caustic soda, aluminous shale. |
| Formosa |  | 42,000 |  |  |  |
| Nippon Aluminum, KK. ..... | Takao, Formosa[1] | 42,000 | 30,112 | 1942 | Bayer process on Bintan bauxite. |
| Manchuria |  |  |  |  |  |
| Anto Keikinzoku, KK. ..... | Antung, Antung, Manchuria | [2](18,000) | None |  | 18,000 ton lime-soda-sinter plant nearly completed for aluminous shale. |
| Manshu Keikinzoku, KK. ... | Fushun, Fushun, Manchuria[1] | 20,000 | 17,200 |  | Calcium aluminate process on aluminous shale. |
| North China |  |  |  |  |  |
| Kahoku Keikinzoku, KK. ... | Chanten, Chanten, North China | [2](20,000) | None |  | 20,000 ton. Lime-soda plant on aluminous shale nearly completed. |

[1] Alumina plants located at reduction works.
[2] Capacities in parenthesis were for plants under construction or planned.
[3] MT = Metric tons.
Sources: Light Metals Control Association, company reports, and Economic and Scientific Section Report No. 9, The Aluminum Industry of Japan, Part I.

TABLE 4. - Alumina production in Japan proper, 1933-45 (metric tons)

| Company | Location | Principal raw material[4] | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 |
|---|---|---|---|---|---|---|---|---|---|
| Asada Kagaku Co., Ltd. ........ | Shikama, Hyogo Pref. | A | 0 | 5 | 203 | 861 | 844 | 982 | 1,190 |
| Dai Nippon Kagaku Co., Ltd. ... | Kawasaki, Kanagawa Pref. | C | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kokusen Keigin Co., Ltd. ...... | Kurosawaziri, Iwate Pref. | C | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mitsui Keikinzoku Co., Ltd. ... | Omuta, Fukuoka Pref. | B | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nippon Aluminum Co., Ltd. ..... | Kurosaki, Fukuoka Pref. | B | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nippon Keikinzoku Co., Ltd. ... | Shimizu, Shizuoka Pref. | B | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nippon Soda Co., Ltd. ......... | Takaoka, Toyama Pref. | B | 0 | 0 | 0 | 0 | 2,391 | 5,772 | 9,831 |
| Nittoh Kagaku Co. ............ | Hachinohe, Aomori Pref. | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Osaka Kogyo Co.[3] ............ | Osaka, Osaka Pref. | AS | 0 | 0 | 0 | 0 | 123 | 992 | 0 |
| Showa Denko Co. (Yokohama) .... | Yokohama, Kanagawa Pref. | B | 100 | 2,419 | 6,079 | 8,693 | 14,287 | 18,347 | 23,263 |
| Showa Denko Co. (Toyama)[2] .... | Toyama, Toyama Pref. | AS | 0 | 0 | 1,053 | 2,389 | 6,214 | 7,644 | 9,156 |
| Sumitomo Kogaku Kogyo Co., Ltd. | Niihama, Ehime Pref. | B | 0 | 0 | 39 | 869 | 1,303 | 3,195 | 5,143 |
| Toyo Keikinzoku Co., Ltd. ..... | Omuta, Fukuoka Pref.[5] | AS | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Toyo Soda Co., Ltd. .......... | Tonda, Yamaguchi Pref. | AS | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total .................... | | | 100 | 2,424 | 7,374 | 12,812 | 25,162 | 36,932 | 48,583 |

| Company | Location | 1940 | 1941 | 1942 | 1943 | 1944 | 1945[1] | Total |
|---|---|---|---|---|---|---|---|---|
| Asada Kagaku Co., Ltd. ........ | Shikama, Hyogo Pref. | 1,127 | 570 | 451 | 633 | 613 | 149 | 7,628 |
| Dai Nippon Kagaku Co., Ltd. ... | Kawasaki, Kanagawa Pref. | 0 | 0 | 0 | 0 | 64 | 2 | 66 |
| Kokusen Keigin Co., Ltd. ...... | Kurosawaziri, Iwate Pref. | 0 | 289 | 0 | 0 | 119 | 88 | 496 |
| Mitsui Keikinzoku Co., Ltd. ... | Omuta, Fukuoka Pref. | 0 | 0 | 0 | 0 | 11,178 | 413 | 11,591 |
| Nippon Aluminum Co., Ltd. ..... | Kurosaki, Fukuoka Pref. | 288 | 14,470 | 17,391 | 21,856 | 11,838 | 1,061 | 66,904 |
| Nippon Keikinzoku Co., Ltd. ... | Shimizu, Shizuoka Pref. | 0 | 17,923 | 64,085 | 113,179 | 71,321 | 3,554 | 270,062 |
| Nippon Soda Co., Ltd. ......... | Takaoka, Toyama Pref. | 12,597 | 13,620 | 19,208 | 22,828 | 17,348 | 1,152 | 104,747 |
| Nittoh Kagaku Co., Ltd. ....... | Hachinohe, Aomori Pref. | 54 | 75 | 176 | 337 | 424 | 19 | 1,085 |
| Osaka Kogyo Co.[3] ............ | Osaka, Osaka Pref. | 18 | 16 | 26 | 13 | 0 | 0 | 1,188 |
| Showa Denko Co. (Yokohama) .... | Yokohama, Kanagawa Pref. | 32,606 | 44,091 | 53,376 | 57,288 | 43,882 | 2,256 | 306,687 |

See footnotes at end of table.

TABLE 4. - Alumina production in Japan proper, 1933-45 (metric tons) (Cont'd.)

| Company | Location | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 1/ | Total |
|---|---|---|---|---|---|---|---|---|
| Showa Denko Co. (Toyama) 2/..... | Toyama, Toyama Pref. | 10,573 | 8,194 | 6,640 | 5,764 | 9,983 | 2,316 | 69,926 |
| Sumitomo Kogaku Kogyo Co., Ltd. | Niihama, Ehime Pref. | 14,587 | 20,068 | 28,412 | 45,734 | 28,895 | 1,662 | 149,907 |
| Toyo Keikinzoku Co., Ltd. ..... | Omuta, Fukuoka Pref. 5/ | 0 | 0 | 0 | 13,956 | 0 | 0 | 13,956 |
| Toyo Soda Co., Ltd. .......... | Tonda, Yamaguchi Pref. | 0 | 0 | 0 | 0 | 1,981 | 1,773 | 3,754 |
| Total .................... | | 71,850 | 119,316 | 189,765 | 281,588 | 197,646 | 14,445 | 1,007,997 |

1/ April to June 30, inclusive.
2/ 1933-1942, Nichiman Aluminum Co., bought by Showa Denko Co. (Toyama).
3/ Converted to cement production in 1938.
4/ B = bauxite; A = alunite; AS = aluminous shale; P = alum phosphate.
5/ Location uncertain.
Source: Natural Resources Section Report No. 44, Mineral Resources of Japan proper, 1925-1945.

TABLE 5. - Alumina production in Formosa, 1937-45, metric tons

| Company | Principal raw material | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nippon Aluminum Co., Ltd., Tokyo | B | 6,438 | 12,288 | 15,914 | 21,896 | 26,609 | 30,112 | 29,908 | 17,970 | 0 | 161,135 |

Source: Natural Resources Section Report No. 44, Mineral Resources of Japan proper, 1925-1945.

TABLE 6. - Alumina production in Korea, 1939-45, metric tons

| Company | Principal raw material | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 1/ | Total |
|---|---|---|---|---|---|---|---|---|---|
| Chosen Keikinzoku Co., Ltd., Chinnanpo 2/... | AS | 0 | 200 | 1,203 | 3,491 | 3,852 | 4,622 | 793 | 14,161 |
| Nippon Chisso Co., Ltd., Konan ........... | AS | 894 | 3,678 | 4,699 | 2,839 | 3,158 | 4,991 | 1,017 | 21,276 |
| Total ................................ | | 894 | 3,878 | 5,902 | 6,330 | 7,010 | 9,613 | 1,810 | 35,437 |

1/ April 1 to June 30, inclusive.
2/ 1939-1942, Chosen Riken Co., Ltd., bought by Chosen Keikinzoku Co., Ltd.
Source: Natural Resources Section Report No. 44, Mineral Resources of Japan proper, 1925-1945.

Bauxite ore and the Bayer process were used for most of the one million metric tons of alumina produced in the Japanese Home Islands and for all of Formosa's 160,000 metric tons. The plants in Korea, Manchuria, and North China had in excess of 200,000 metric tons rated annual capacity, based on the use of aluminous shale. They were in all stages of development, including large-scale industrial plants in production, others nearly completed, some just started, and others on blueprints at the time of surrender. The persistent and far-from-fruitless efforts of the Japanese to extract alumina from raw materials other than bauxite ores stemmed from the entire absence of proven deposits of commercial-grade bauxite in Japan and from the existence of extensive deposits of high-grade aluminous shales and clays in Manchuria and North China. Accomplishments in processing these materials were noteworthy and might well have advanced much farther, had Korean and Manchurian works under construction gotten into full-scale production. Over a 10-year period, the Asada Kagaki Kogyo, K.K., produced 7,600 metric tons of alumina from alunite. Several other Japanese concerns did laboratory and small-scale pilot-plant work on alunite and on domestic clays. So far as could be ascertained, nothing of promise resulted from the clay work. The Nittoh Kagaku Kogyo, K.K., produced about 1,000 tons of alumina as a byproduct in processing phosphate rock for fertilizer.

The raw materials required per ton of alumina for various processes are shown in table 7. The composition of bauxites and aluminous ores, together with their source, are listed in table 8.

## Bayer Process

The Bayer hydrometallurgical process for the manufacture of alumina from bauxite ores has become standard practice for industrial production of high-purity alumina suitable for reduction to metal by the Hall-Herault electrolytic method. The Bayer process is based on the use of dilute caustic soda solution under such conditions of pressure and temperature that alumina is extracted from the ore as sodium aluminate and is held in solution while the iron and most of the silica remain undissolved. All this is possible because alumina possesses the peculiar chemical characteristic of acting either as a base or an acid. When behaving as an acid, it will react with alkali to form aluminate. The resulting sodium aluminate solution is separated from the insoluble residue, usually by counter-current decantation, is then clarified, and the alumina precipitated from the solution as alumina trihydrate by hydrolysis. Excess caustic liquor, which carries the aluminate, is evaporated to reduce solution volume and for recovery of caustic for reuse in the leaching of ore. The alumina trihydrate is separated from solution, washed, filtered, and calcined to alumina, ready for reduction to metal in electrolytic cells. Figure 5 shows a rotary calcining kiln at the Shimizu alumina plant.

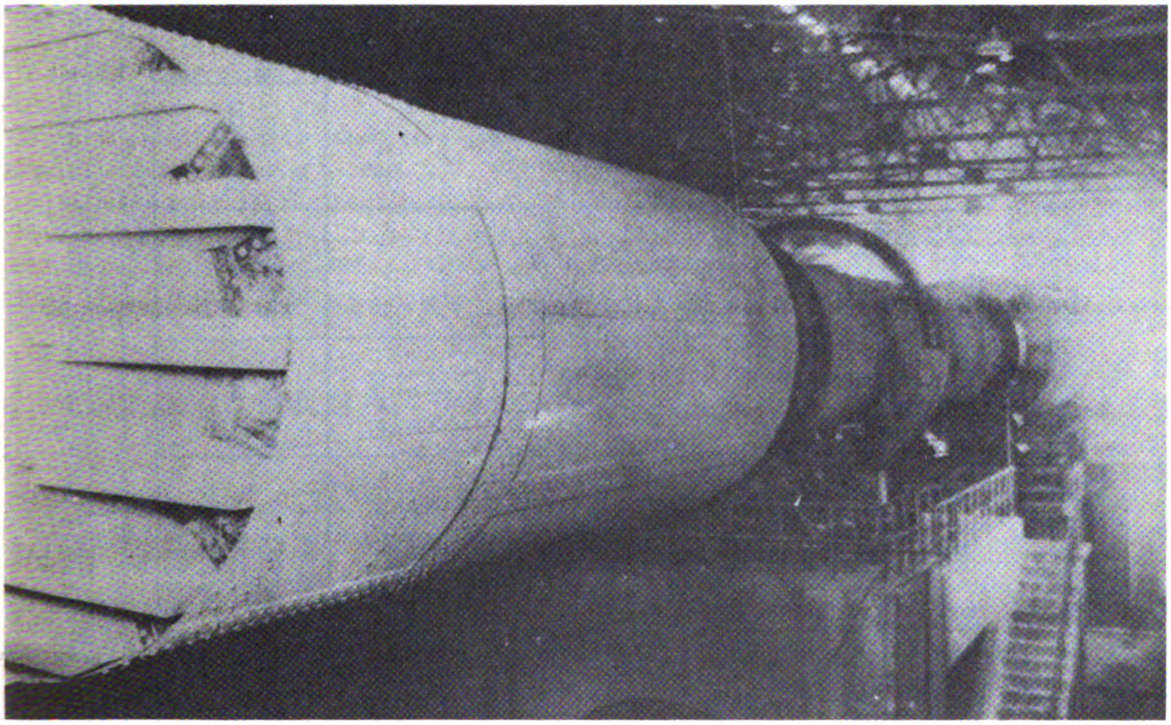


Figure 5. - Rotary calcining kiln at Shimizu alumina plant of Nippon Keikinzoku, K. K.

TABLE 7. - Raw materials required per ton of alumina, metric tons

| Materials used | Metric tons | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Best Japanese Bayer plants, normal | Designer's estimate for Shimizu Bayer | Shimizu actual Bayer | Shimizu LSS[1] | Nippon soda Bayer | Kurosaki Bayer | Toyama Al shale | Toyo soda LSS on Al-shale clinker to $Al(OH)_3$ | Kurosaki LSS |
| Column No.[2] 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Bauxite ..................... | 2.300 | 2.280 | 2.28 | | 2.30 | 2.250 | | | |
| Coal ........................ | 2.000 | 1.300 | 2.33 | | | 3.170 | 0.67 | 0.40 | |
| Soda ash .................... | 0.100 | 0.100 | 0.10 | 1.0 | | | | | 2.27 |
| Limestone ................... | 0.175 | 0.180 | 0.09 | | | | | 2.60 | |
| Caustic soda ................ | | | | | 0.12 | 0.116 | | | 1.71 |
| Steam ....................... | | 8.900 | | 12.0 | | | | 14.00 | 19.00 |
| Water ....................... | | 18.500 | 17.60 | 40.0 | | 3.000 | | 6.00 | |
| Anthracite .................. | | | | | | | 0.74 | 0.40 | |
| Aluminous shale ............. | | | | | | | 2.70-3.40 | | |
| Clinkered al-shale .......... | | | | 7.0 | | | | 5.00-5.70 | 6.38 |
| Producer gas (1,000 cu.m.). | | | | 6.3 | | | | | |
| Scrap iron .................. | | | | | | | 0.29 | | |
| Electrode ................... | | | | | | | 0.54 | | |
| Coke ........................ | | | | | | | | | |
| Sulfuric acid ............... | | | | | | | 0.30 | | |
| Power, Kwhr.................. | 480-570 | 480 | 530 | 330 | | | 12,320 | 700 | |

[1] LSS - Lime-soda-sinter.

[2] Col. 3. Plant designed by H. Tiedemann.
Col. 4. 1.15 tons for producer gas; 1.18 tons for boilers (2.33).
Col. 10. 98 percent $Na_2CO_3$ (2.27).
Col. 4. Burned lime (0.09).
Col. 9. Clinker; LOI 3.6 percent; $Al_2O_3$, 32.8 percent; $SiO_2$, 14.8 percent; $Fe_2O_3$, 5.6 percent; CaO, 21.2 percent; $Na_2O$, 20.8 percent (5.00-5.70).
Col. 8. Acid not always used (0.30).
Col. 8. Or equivalent ferruginous material, depending on Fe content of shale (0.29).
Col. 4. Made by back-pressure turbines from 1.18 tons coal burned under boilers (530).

Source: Company reports in plants listed in column headings.

TABLE 8. - Chemical composition of bauxites and aluminous raw materials used in Japan, weight percent

| Sources | $H_2O$ | LOI | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | $P_2O_5$ | $Na_2O$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Column No. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Bauxites:** | | | | | | | | | |
| Bintan | 10.87 | 29.25 | 55.22 | 3.93 | 10.24 | 0.78 | 0.07 | ND | Analysis by Sumitomo, best grade. |
| Do. | 11.56 | 27.90 | 52.35 | 4.93 | 13.24 | 0.90 | 0.08 | ND | Analysis by Sumitomo, poorest grade. |
| Do. | 8.00 | 28.95 | 54.99 | 2.82 | ND | ND | ND | ND | Analysis by Sumitomo. |
| Do. | 10.70 | 28.56 | 55.62 | ND | ND | ND | ND | ND | Do. |
| Johore | 8.30 | 30.23 | 55.99 | 4.55 | 7.77 | 1.24 | ND | ND | |
| Malacca | 8.60 | 26.96 | 51.00 | 5.72 | 15.50 | 0.63 | ND | ND | |
| French Indo-China | ND | 13.07 | 53.76 | 4.77 | 24.74 | 2.60 | ND | ND | CaO, 0.10 percent. |
| Palau (Paraō) | 16.12 | 29.11 | 52.66 | 2.75 | 14.17 | ND | ND | ND | Analysis by Sumitomo. |
| Do. | 16.67 | 28.69 | 51.68 | 2.95 | 15.02 | ND | ND | ND | Do. |
| Do. | 15.54 | 29.40 | 52.85 | 2.67 | 13.68 | 1.05 | 0.05 | ND | Do. |
| Do. | 17.36 | 28.27 | 51.26 | 3.50 | 15.07 | 1.02 | 0.05 | ND | Do. |
| Malay, Johore | 8.00 | 28.95 | 54.99 | ND | ND | ND | ND | ND | Do. |
| Do. | 10.70 | 28.56 | 55.62 | 1.21 | 9.48 | 4.93 | 0.03 | ND | Do. |
| Do. | 6.30 | 28.19 | 52.53 | 3.24 | 14.17 | 0.85 | ND | ND | Do. |
| Clinker from aluminous shale | 0.14 | 0.71 | 35.34 | 15.05 | 9.03 | 1.38 | ND | 18.95 | CaO, 19.32; $CO_2$ = 0.14 percent; by Sumitomo. |
| Asano Cement Co., Yamaguchi Pref. | ND | 1.31 | 23.66 | 13.10 | 13.63 | 0.51 | ND | 24.15 | CaO, 23.66; MgO, 0.58 percent. |
| Onoda Cement Co., Yamaguchi Pref. | ND | 1.98 | 33.67 | 12.77 | 9.45 | 0.91 | ND | 21.02 | CaO. 18.87; Mgo, 0.29 percent. |
| Toyo Soda, Kabushiki Kaisha | ND | 3.60 | 32.78 | 14.75 | 5.64 | ND | ND | 20.80 | CaO, 21.20 percent; analysis by Sumitomo. |
| Onoda, Yamaguchi Pref. | 0.91 | 3.83 | 28.82 | 12.98 | 8.23 | 1.20 | ND | 22.32 | CaO, 19.72 percent; $CO_2$, 1.43 percent; analysis by Sumitomo. |

See footnotes at end of table.

TABLE 8. - Chemical composition of bauxites and aluminous raw materials used in Japan, weight percent (Cont'd.)

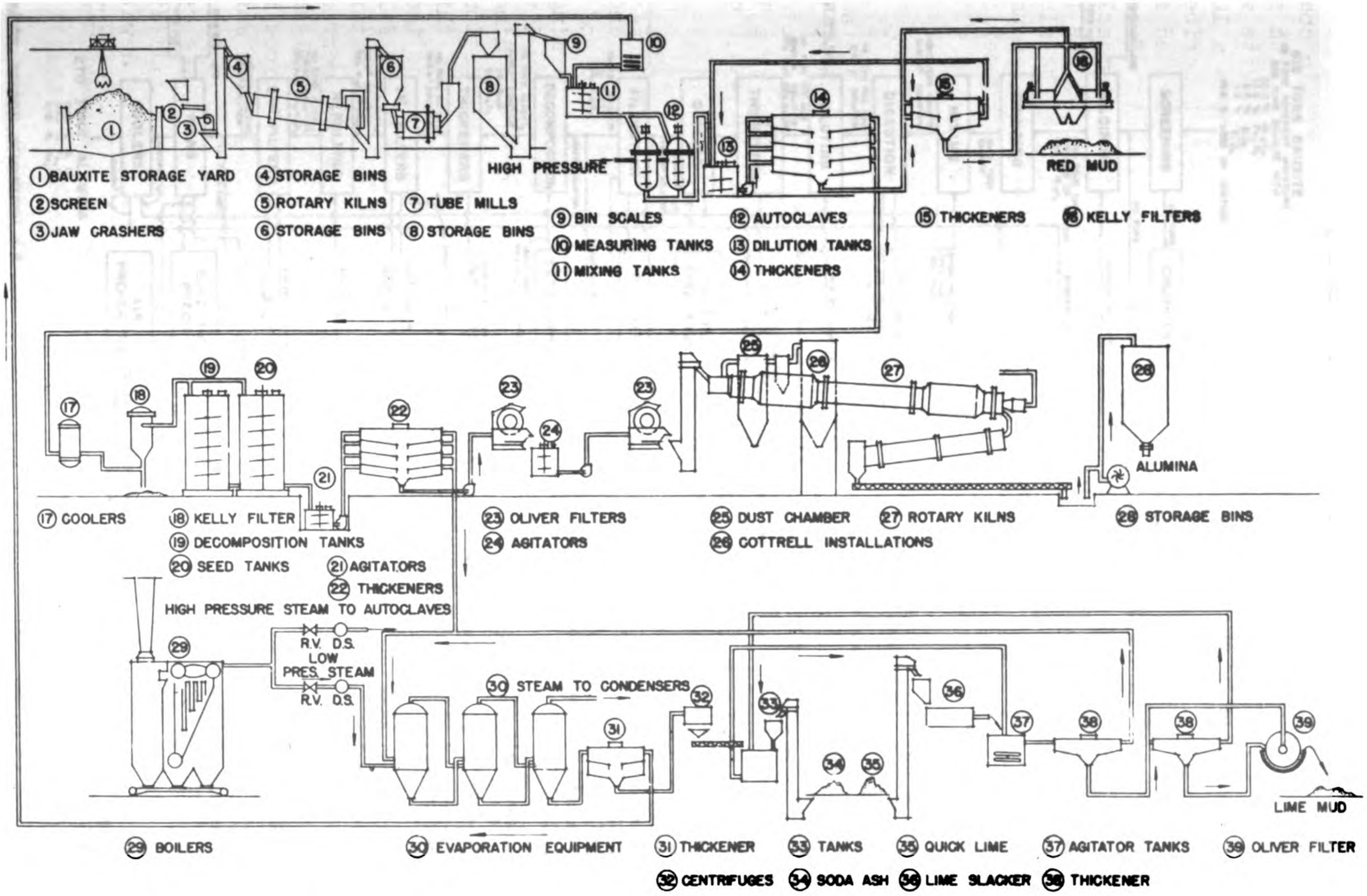
| Sources | $H_2O$ | LOI | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | $P_2O_5$ | $Na_2O$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Column No. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Aluminous shale, North China: | ND | 13.53 | 56.13 | 17.60 | 8.35 | ND | ND | ND | Analysis by Sumitomo. |
| Aluminous shale, North China... | 1.31 | 13.61 | 59.56 | 12.97 | 9.34 | 2.40 | ND | ND | Do. |
| Do. .............. | 1.16 | 13.46 | 52.74 | 22.24 | 7.36 | 2.40 | ND | ND | Do. |
| Do. .............. | ND | 13.62 | 55.31 | 17.72 | 10.96 | 1.63 | ND | ND | CaO, 0.19 percent, MgO, 0.44 percent, analysis by Nippon Keikinzoku, K.K. |
| Do. .............. | ND | 13.80 | 57.91 | 15.14 | 11.58 | 1.50 | ND | ND | Analysis by Nippon Alumi Kurosaki |
| Alunite: | | | | | | | | | |
| From Mt. Gyokumai, Korea ...... | 0.36 | 8.51 | 36.02 | ND | 23.45 | ND | ND | 0.96 | $SO_3$, 23.58 percent; $K_2O$, 5.78 percent; analysis by Sumitomo. |
| Izu, Penn Shizuoka Pref. ...... | ND | 34.70 | 42.10 | 8.90 | ND | ND | ND | 2.82 | $SO_3$, 31.2 percent; $K_2O$, 3.65 percent; analysis by Nippon Keikinzoku, K.K. |
| Do. ................. | 6.84 | 13.70 | 36.35 | 5.39 | 0.54 | 0.41 | ND | 3.16 | Col. 2 at 600° C.; $SO_3$, 35.78 percent; $K_2O$, 4.62 percent. |
| Clay: | | | | | | | | | |
| Kumamoto Pref. ................ | ND | 12.49 | 32.90 | 39.26 | 11.70 | 2.34 | ND | ND | Col. 10 MgO, 0.79; analysis by Sumitomo. |
| Kagawa Pref. ................. | ND | 14.80 | 31.34 | 30.52 | 9.64 | 1.40 | ND | ND | Col. 10 MgO, 0.99; analysis by Sumitomo. |
| Yame, near Kurosaki .......... | ND | 21.71 | 41.56 | 25.76 | 10.16 | 1.40 | ND | ND | |

ND = No data available.
Col. 3 = LOI is loss-on-ignition.
Source: Company reports, mostly those listed in columns 1 and 10.

In the better Japanese Bayer plants, bauxite was off-loaded from ships, often to ground storage, from which it was reclaimed as needed and sent to the ore-preparation section of the plant. This consisted of suitable coarse-crushing equipment, rotary dryer, and thermal ball mill in circuit with air classifiers. In all plants except one in Yokohama, the crushed bauxite was dried to remove moisture and organic matter. Dry ore ground to pass a 100-mesh sieve was considered suitable for leaching. The steps just described are indicated by items 1 to 8 in figure 6. Measured amounts of ore and strong caustic (NaOH) mill solution, corrected to contain definite amounts of caustic and alumina, were intimately mixed and dropped as a batch into steam-jacketed autoclaves (12) and digested for several hours at 150° C. and 70 pounds per square inch pressure. Under such conditions, about 90 percent of the alumina in the ore goes into solution as sodium aluminate, whereas iron, titanium, and most of the silica are undissolved. At the end of the leaching period the contents of the autoclaves were blown into cooling tanks, diluted with solution from the secondary washing thickeners (15), and pumped to primary tray thickeners (14) for separation of pregnant sodium aluminate solution from insoluble residue. The latter was pumped to washing thickeners (15), then to pressure filters (usually horizontal Kelly presses). The cake was red mud or plant residue and was impounded in waste ponds. The alumina lost in this residue often represented 20 percent or more of the alumina content of the original bauxite ore entering the plant and was accompanied by a loss of at least 130 kilograms of caustic soda per ton of alumina produced. The Japanese did not re-treat the red mud.

The pregnant caustic sodium aluminate liquor overflowing the primary thickeners was cooled, clarified (usually in vertical Kelly presses), and pumped to decomposition tanks (19), where it underwent 24 to 36 hours of gentle agitation and cooling while alumina trihydrate $Al(OH)_3$ was forming. To induce the hydrate to form large crystals, seed crystals of finely divided alumina trihydrate were added to the precipitation tanks from a preceding batch. About half of the contained sodium aluminate in the decomposition tanks was precipitated from solution as trihydrate, thickened in tray thickeners (22), filtered, repulped, and filtered again before delivery to the calcining kilns (27) for dehydration. Overflow of the thickeners and filtrates from the washing filters or washing thickeners, if used in lieu of filters, were sent to evaporators (30), then to thickeners. The thickener overflow was concentrated caustic-sodium aluminate mill solution for reuse in leaching a fresh batch of ore. Soda ash in the thickener underflow was dewatered by centrifuges and sent to soda-ash-dissolving tanks, where new soda-ash makeup was introduced into the circuit. Quicklime also was added at this point to causticize soda ash. Causticizer discharge was washed, thickened, and filtered. Thickener overflows were used for make-up solution in the soda dissolving tank or returned to the evaporators for concentration. The dewatered trihydrate of alumina from the filter was calcined at 1,000° C. in rotary kilns, cooled, and delivered to alumina storage bins.

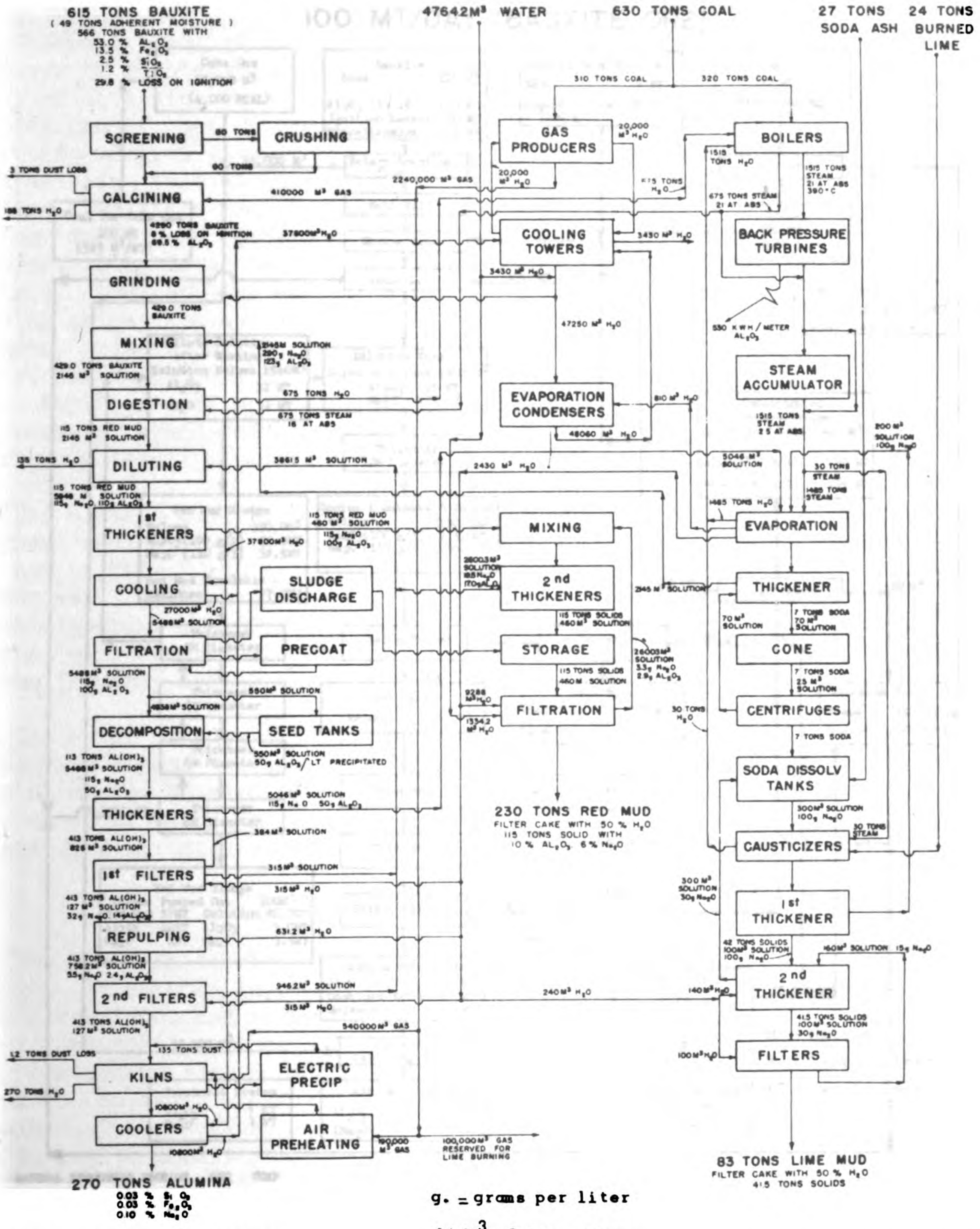
In principle, the process is quite simple. In practice, the operations, though now standardized to a great extent, are far from simple and require training and skill and good instrumentation for control of critical steps. With some exceptions, Japanese alumina plants lacked skilled operators and



NATURAL RESOURCES SECTION GHQ SCAP

Figure 6. - Diagramatic flow sheet, Bayer process.

( 270 TONS $AL_2O_3$ PER DAY )



g. = grams per liter

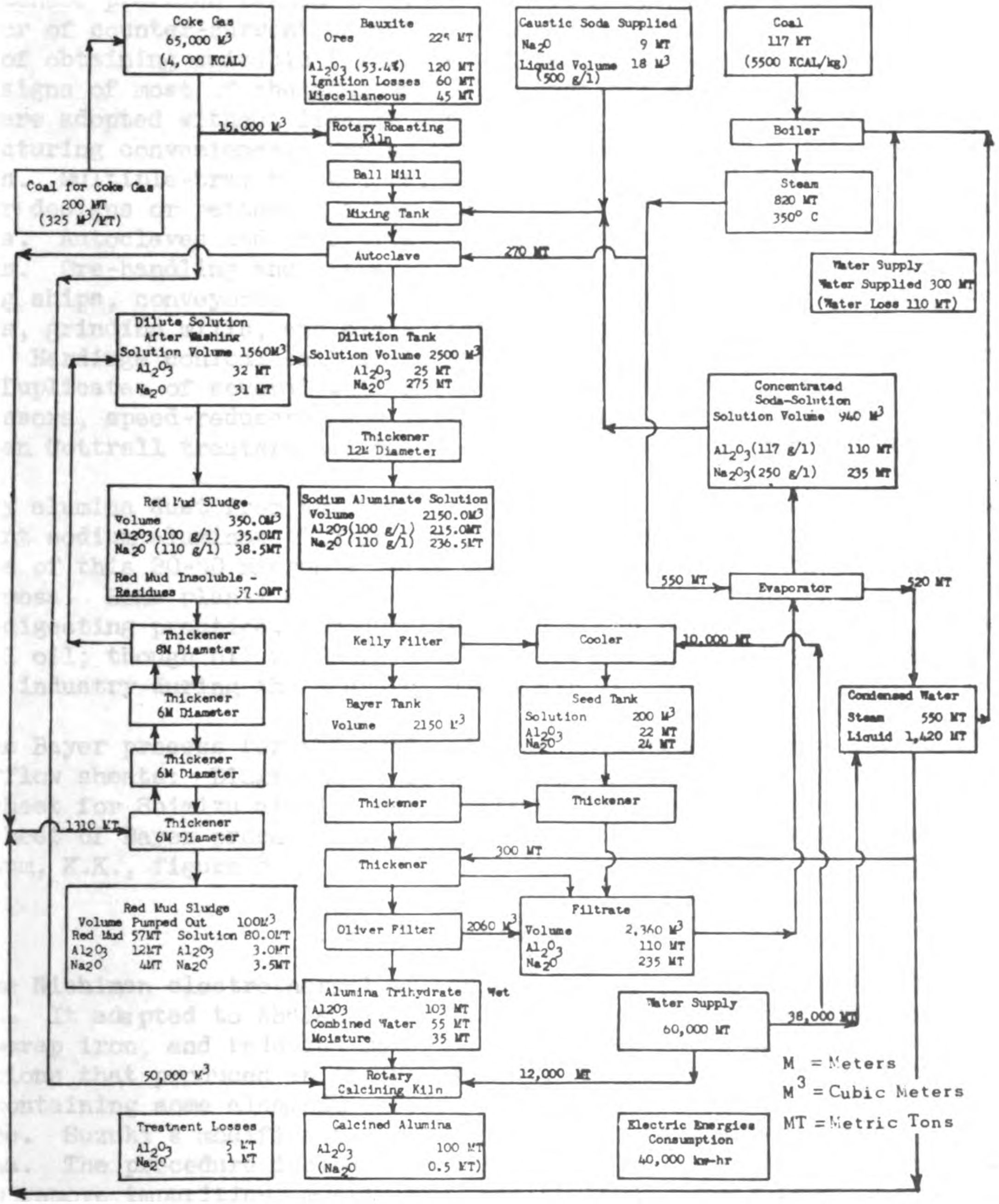
1/ M³ = Cubic meters.

SOURCE: NIPPON KEIKINZOKU K K

NATURAL RESOURCES SECTION GHQ SCAP

Figure 7. - Balanced flow sheet for Shimizu alumina plant.

100 MT/DAY (BAUXITE ORE)



NATURAL RESOURCES SECTION GHQ SCAP

Figure 8. - Flow sheet and material balance sheet of Bayer process for producing alumina, Kurosaki plant, Nippon Aluminum, K. K.

proper instrumentation; therefore, material consumption and plant losses were high.

Japanese practice tended to avoid filtering operation as much as possible in favor of counter-current decantation washing owing to the cost and difficulty of obtaining suitable filter media, particularly cotton goods. Types and designs of most of the equipment are identical with American manufactures. Some were adopted without license and sometimes changed slightly to suit local manufacturing convenience. Drying and calcining kilns were chiefly German designs. Multiple-tray thickeners, diaphragm pumps, and filters were built on Dorr designs or patterned after Dorr, Oliver, Kelly, and other American designs. Autoclaves and precipitation tanks appeared to follow American designs. Ore-handling and preparation equipment such as machinery for unloading ships, conveyors, distributors, continuous weighing machines, ore feeders, grinding mills, and classifiers are mostly exact replicas of American types. Hardinge conical ball mills are favorites for both wet and dry grinding. Duplicates of several well-known makes of sand pumps, vacuum pumps, compressors, speed-reducers, and V-belt power-transmission systems were noted. American Cottrell treaters and dust-collecting equipment were in common use.

Dry alumina dust from the Cottrells was sometimes used for seeding the pregnant sodium aluminate liquor for precipitation of alumina trihydrate. The use of this 20-50 micron alumina dust was developed at the Takao works in Formosa. Some plants employed continuous leaching of ore instead of the batch-digesting practice. Producer gas was generally used in Japan in place of fuel oil; though oil was more suitable, it was not available in quantity to the industry during the years of World War II.

The Bayer process for the production of alumina is further described by three flow sheets: Diagrammatic flow sheet, Bayer process, figure 6; balanced flow sheet for Shimizu alumina plant, figure 7; flow sheet and material balance sheet of Bayer process for production of alumina, Kurosaki Plant Nippon Aluminum, K.K., figure 8.

## Electric Fusion Process

The Nichiman electrothermal process was developed and patented by Yasuo Suzuki. It adapted to shale one of Hall's early methods for bauxite, wherein ore, scrap iron, and reducing material were fused in an electric furnace under conditions that produced an impure alumina, ferrosilicon, and a mixture of the two, containing some aluminum carbide and nitride, which was returned to the furnace. Suzuki's modification pertained mostly to the purification of crude alumina. The procedure included crushing, heating, chlorinating, and leaching to remove impurities, mostly iron and silicon. Their removal, under the conditions prescribed, also served to disintegrate the alumina, an important item, because the lump alumina was tough, abrasive, and difficult to pulverize. Failure of the Suzuki modification was attributed to the superficial nature of the chlorination. Chlorine did not completely penetrate the lumps. Corrosion difficulties also were encountered.

Chlorination was soon abandoned in favor of other methods of purifying the alumina, but no completely satisfactory method had been evolved. Two fairly effective substitute methods for purifying the crude alumina were developed and used industrially at the Toyama works. The one most used consisted of heating the crushed, selected alumina in a retort furnace to 800° C. and treating it with steam. This produced the dual results of dissolving soluble impurities and at the same time leaving the alumina in granular condition. The steaming was said to be intermittent, and about 14 hours were required for a complete cycle of purification operations. Retorts were charged and discharged by hand.

In an alternate method, selected alumina was ground and leached with sulfuric acid. Wet grinding in acid was tried experimentally, followed by separation of the sulfate solution from the solid alumina. This method was said to be ineffective alone and had definite short-comings, including failure to remove ferrosilicon. Near the end of the war, it apparently was applied only to very low-grade electrothermal alumina.

The purification procedure used at Chosen Keikinzoku, K.K., Korea, differed somewhat from that followed at Toyama. The crude alumina was first leached with caustic-soda solution, which dissolved about 20 percent of the alumina. This was precipitated by Bayer-process decomposition, filtered, and calcined. About 80 percent of the alumina remained insoluble and was said to have been treated with both sulfuric and nitric acids, dried, and mixed with the Bayer alumina. Additional Bayer alumina was imported from the Japanese Home Islands for reduction to aluminum at this plant.

The Japanese had two plants in operation, and a third and much larger one planned using an electrothermal alumina process known in Japan as the electric fusion or Nichiman process. The original plant of Showa Denko, K.K., at Toyama (see fig. 8), was nominally rated at 12,000 metric tons "dry"[5] alumina annually; Chosen Keikinzoku, K.K.'s plant at Chinnanpo, Korea, was rated at 5,400, and up to 8,000 metric tons capacity was planned. Chosen Sumitomo Keikinzoku K.K's works at Genzan, on the east coast of northern Korea, originally planned to build a works to produce 100,000 metric tons of alumina and 50,000 metric tons of metal. Construction started in midyear 1943, and over one million yen had been spent. This plant was abandoned, on account of increasing difficulties in procuring materials and equipment, in favor of a works to produce 36,000 metric tons alumina and 25,000 tons of ingot. Construction was well-advanced on the first units of the reduction works, but all work ceased in August 1945. Late that year the plant was dismantled and moved by the Russian occupational forces.

As the Toyama works was the prototype for the plants in Korea and Manchuria, details of its operation are of technical interest. Practice was not standardized, and weaknesses of the process were recognized. Toyama was designed to treat aluminous shale from Manchuria and did so until more economical hard bauxite ore, containing more iron and less silica, was obtained from Greece. When this supply was cut off by war in Europe, a similar and quite satisfactory bauxite was obtained from French Indo-China. This likewise was cut off, so high-grade hard aluminous shale from Shantung Province, North China, was substituted. Typical analyses of these ores are:

---

[5] Alumina produced by the electrothermal process in Japan was referred to as "dry," to distinguish it from Bayer alumina.

TABLE 9. - Alumina ores treated by electric fusion process to produce alumina

| Ore | Analyses, percent | | | | | |
|---|---|---|---|---|---|---|
| | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | CaO | $TiO_2$ | Loss on ignition |
| Greek bauxite ............... | 52.00 | 6.51 | 21.94 | 0.10 | 2.84 | 12.50 |
| French Indo-China bauxite ... | 53.76 | 4.77 | 24.74 | .10 | 2.60 | 13.07 |
| North China aluminous shale.. | 57.35 | 15.18 | 10.77 | .35 | 1.83 | 14.28 |

Raw materials and secondaries were batched on the charge floor and hand-charged into open-top, rectangular arc furnaces for smelting. Three solid, pole-graphite electrodes were lowered into the bath from the top. The furnaces were rated at 4,000 kilowatts and were supplied with 18,000 amperes of alternating current at 150 volts. The oxides of iron, silicon, and titanium are reduced to metal. The aluminum compounds form alumina, metal, and aluminum carbide. A typical charge when treating low-iron aluminous shale is:

| Furnace charge | Kilograms |
|---|---|
| Aluminous shale (57 percent $Al_2O_3$)......... | 3,600 |
| Anthracite coal ........................... | 1,000 |
| Scrap iron ................................ | 500 |
| Furnace secondaries ....................... | 800 |

Every 4 to 5 hours molten products were tapped from the bottom of the furnace into cast-iron, cone-shaped ladles about 5 feet in diameter and allowed to cool for 24 hours. During cooling, the contents of the ladle segregate by gravity into three quite distinct layers. The alumina is on top, ferrosilicon-aluminum alloy on the bottom, and a layer of mixed materials that sometimes represents 25 percent of the weight of the ladle contents in the middle. In cooling, a small amount of aluminum nitride is formed in the top layer exposed to the atmosphere. The ladle is turned upside-down, and the solid cone-shaped contents are dumped on the sorting floor. The ferrosilicon alloy on top of the cone was easily broken into large lumps and sorted. The middle layer of mixed products was sorted out and returned to the charge floor for remelting along with as much of the aluminum nitride as could be collected.. The crude "lumpish" alumina was sorted and purified. The fraction containing the smaller amounts of iron, silica, and titania was treated by the retort process, and the rest was ground and treated with acid.

Electrothermal alumina contained more impurities than Bayer. Annual average for "retort" alumina in 1943, when treating North China aluminous shale, was in percentage, 0.22 $SiO_2$, 0.08 $Fe_2O_3$, and 0.11 $TiO_2$; corresponding percentages for alumina from the "acid" purification processes were 0.24, 0.12, and 0.15.

Figure 9 is a generalized flow sheet of the electric fusion process as operated at Toyama. About 20,000 metric tons of "dry" alumina were produced from high-aluminous shale.

## Lime-Soda-Sinter Process

As the supply of bauxite became more difficult to maintain, owing to the progress of World War II, Japanese metallurgists began to develop a lime-soda-sinter process for use on domestic raw materials and particularly for the high-aluminous shales obtainable from the nearby Asiatic mainland. These shales, from Manchuria and North China, were not amenable to the Bayer process, so full-scale industrial operations to treat them by the lime-soda-sinter process were undertaken. The principles employed in our lime-soda-sinter processes recently described by Conley, Cservenyak, and others in Federal publications and technical magazines in the United States[6] were followed.

The process consists of sintering or making a clinker of a mixture of crushed aluminous material, crushed limestone, and soda ash in a rotary kiln at temperatures up to 1,200° C. The soluble salts of aluminum in the crushed clinker are leached out with water or dilute alkaline solutions and separated from the insoluble material desilicated and reacted with carbon dioxide gas (Deville process) to form alumina trihydrate and sodium carbonate, or the aluminate liquors are treated by the Bayer process. The precipitation of alumina trihydrate by carbon dioxide gas was used exclusively in only one plant in Japan, that of Toya Soda, K.K. Nippon Aluminum prepared to use both carbon dioxide and the Bayer-seed methods at its Kurosaki plant (see fig. 10).

The Japanese government, near the end of World War II, ordered several cement manufacturers to revamp their plants that contained suitable kilns and go into production of lime-soda-sinter. Over 100,000 metric tons of sinter containing 29 to 35 percent alumina and 19 to 24 percent soda were produced from 1943 to 1945 and distributed to existing alumina plants.

In northern Korea, a lime-soda-sinter plant was built in 1939 and operated by Nippon Chisso, K.K. This plant was intended to produce 8,000 to 10,000 metric tons alumina annually from aluminous shale and had under construction additional units to nearly double the original capacity. Actual production never exceeded 5,000 metric tons of alumina per year. Plants in Manchuria and northern China were nearing completion at the close of World War II.

A material balance flow sheet for the lime-soda-sinter process at the Kurosaki plant is given in figure 10.

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[6] Conley, J. E., et al, Production of metallurgical alumina from Pennsylvania nodular diaspore clays: Bureau of Mines Bull. 465, 1947, 193 pp., 68 figs.
Cservenyak, F. J. Recovery of alumina from kaolin by the lime-soda-sinter process: Bureau of Mines Report of Investigations 4069, May 1947, 59 pp.
Edwards, Frary, and Jeffries, The Aluminum Industry: McGraw-Hill, New York, 1940.

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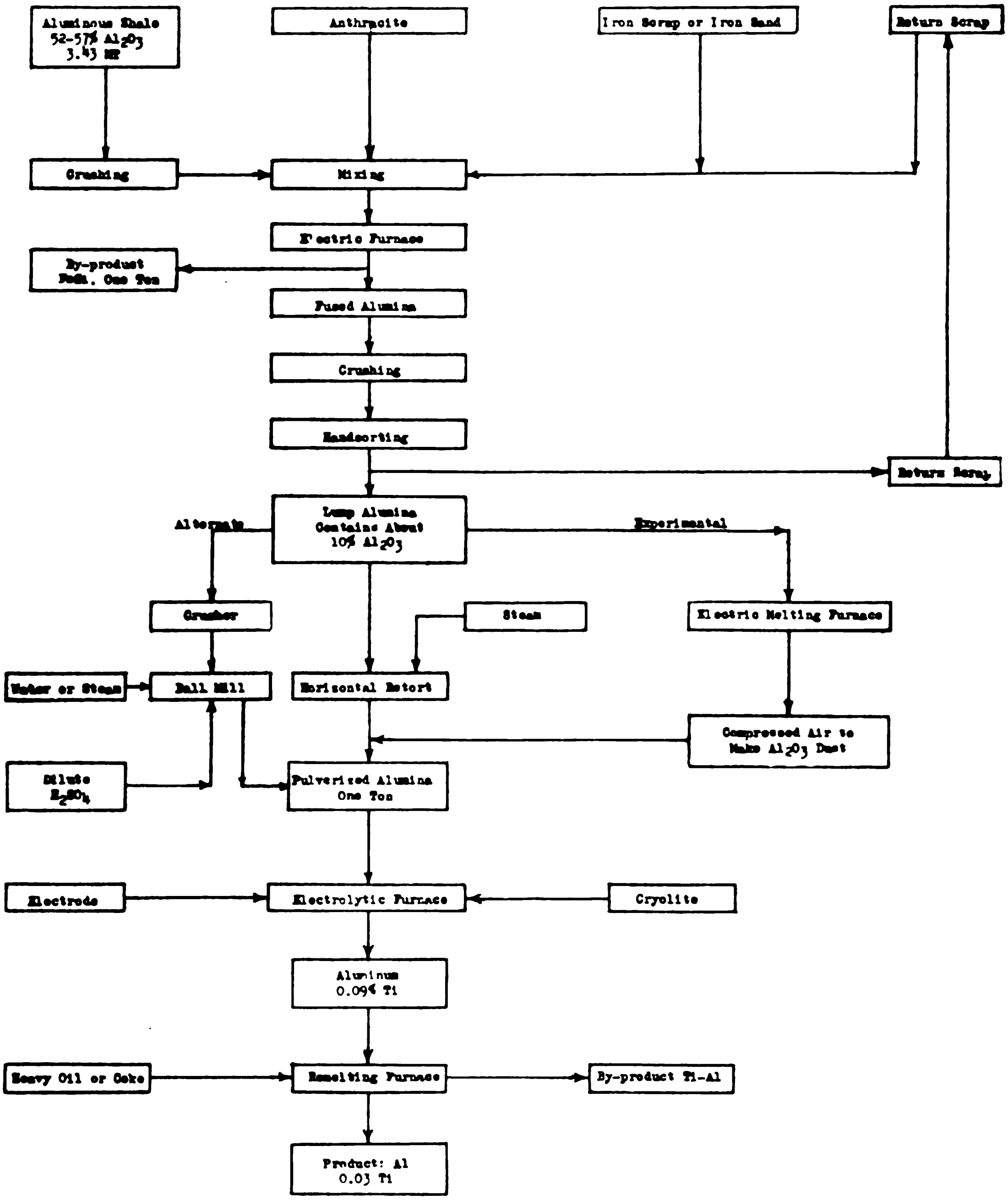
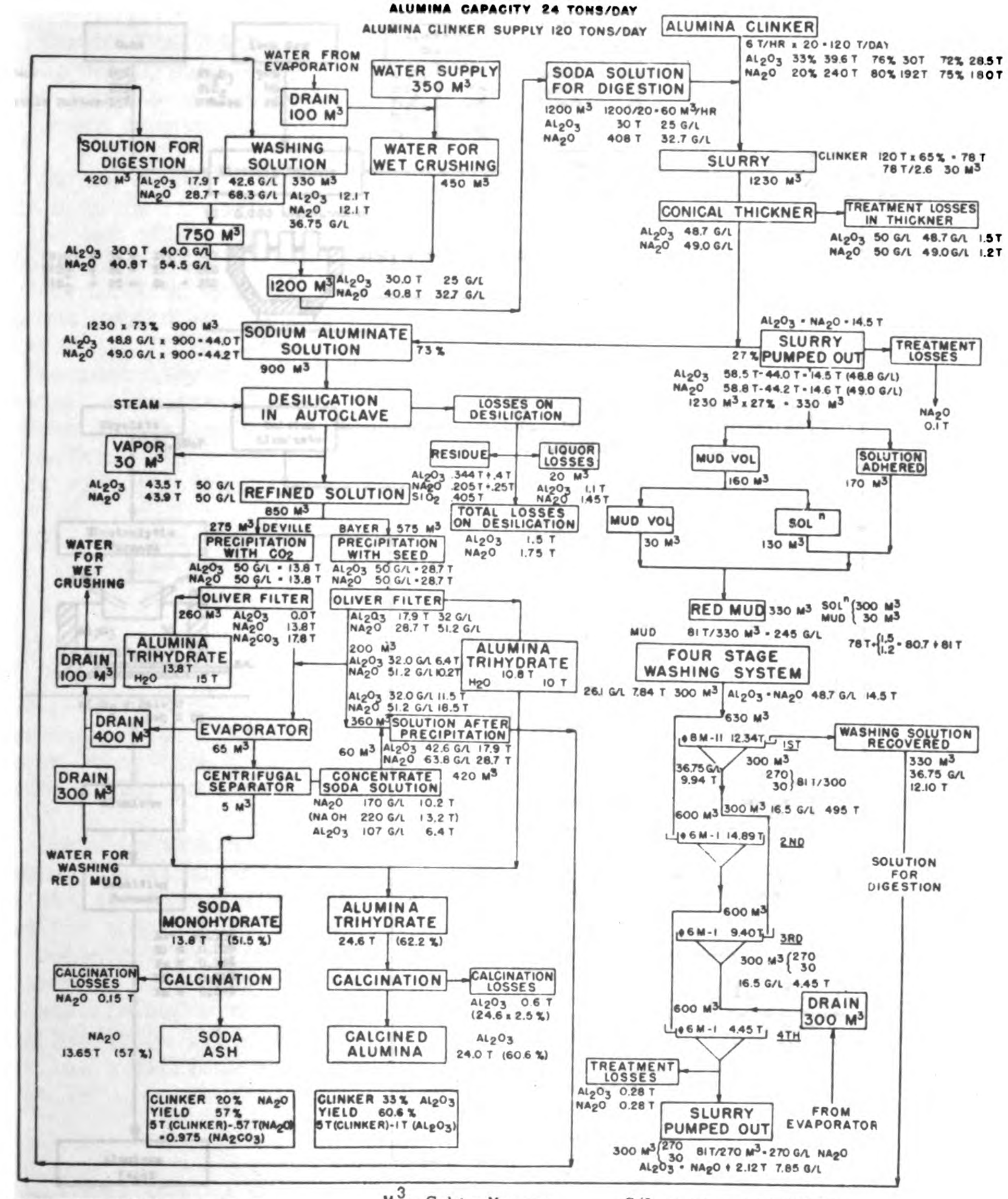
# FLOWSHEET
# OF
# ELECTRIC FUSION PROCESS FOR ALUMINA
## TOYAMA WORKS, SHOWA DENKO, KK



NATURAL RESOURCES SECTION GHQ SCAP

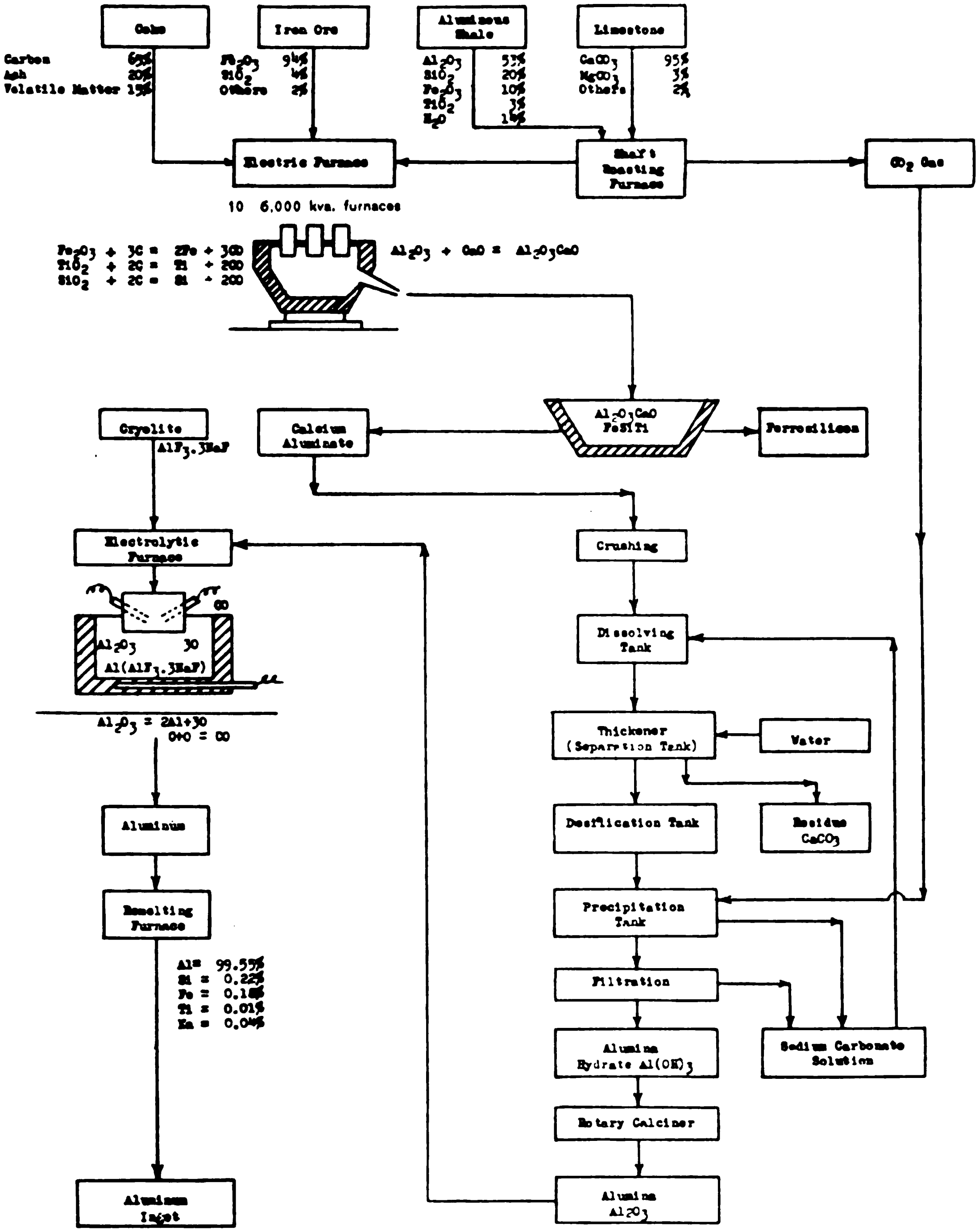
Figure 9.



NATURAL RESOURCES SECTION GHQ SCAP

$M^3$ = Cubic Meters G/L = grams per liter

Figure 10. - Flow sheet and material balance of lime-soda process for producing alumina from lime soda sinter or clinker, Kurosaki plant, Nippon Aluminum, K. K.



NATURAL RESOURCES SECTION GHQ SCAP

Figure 11. - Flow sheet of Fushun Aluminum Works, Manshu Keikinzoku, K. K.

## Calcium Aluminate Process

Manshu Keikinzoku, K.K., operated a plant at Fushun, Manchuria, near Mukden, employing a calcium aluminate process similar to the Pederson method. Meager details of the technical operations were reported by Shigero Kabayashi, the former Japanese government Chief of Sections of Manchurian Affairs.

At the Fushun plant, aluminous shale and limestone were calcined with pitch coke in 11 shaft furnaces 3 meters diameter and 6 meters high. The calcine was mixed with coke and iron ore, or the equivalent iron as iron shale, and treated in ten 6,000-kv.-a. furnaces. The liquid calcium aluminate and ferrosilicon were tapped about every 6 hours. The sorted calcium aluminate was ground dry in tube mills. The finely ground aluminate was leached in agitators at 70° C. with plant solution containing 70 grams per liter $Na_2O$. The pregnant liquor was separated from the solid residue by countercurrent decantation in thickeners. The liquor was desilicated, and carbon dioxide gas from lime kilns was used to precipitate the alumina trihydrate. Soda ash was reclaimed from the solution and recycled to the leaching agitators for use as work solution.

The calcium aluminate process as used at the Fushun aluminum works is shown in figure 11.

## Caustic Soda Process for Shale

Chosen Denko, K.K., is reported to have had a 105,000-metric ton plant under construction at Chinnanpo, Korea, for the production of alumina from aluminous shale. Little could be learned of the technical aspects of the process other than that the aluminous shale was to be treated with strong caustic liquor containing 600 grams sodium hydroxide per liter.

The Shimizu alumina plant of Nippon Keikinzoku, K.K., tested a process known as the alkali-fusion or Nikkei method on alunite and on sintered aluminous shale. Sodium aluminate work liquor from the Bayer plant was substituted for soda ash in the sintering step in the preparation of aluminous shale that contained kaolinite and diaspore. The clinker was more brittle than that produced by sintering with limestone and soda ash. Higher extraction of alumina was claimed with lower loss of alkali. The process did not get out of the pilot stage owing to the formation of hard, massive ring concretions in the kiln, a difficulty not yet overcome when the plant suspended operation in August 1945.

## Processes Used on Alunite

The alunite processed in the Japanese Home Islands was obtained mostly from Ugusu on the Izu Peninsula. The crude alunite contained about 32 percent alumina, 6 to 20 percent silica, 4 percent potash, and 3 percent sodium oxide. Much of the silica was in the form of quartz that could be separated by flotation and thus reduce the consumption of caustic soda.

Alunite was abandoned as a source of alumina by the Yokohama and Shimizu plants in favor of bauxite, for technical and economic reasons, when large-scale production of aluminum got underway. When imported bauxite supplies became difficult to obtain, several companies returned to experimental use of alunite as a source of alumina. Most of these later efforts were pilot-plant operations using some of Bayer-plant equipment.

The Tanaka caustic-soda process for alunite shown in figure 12 (Japanese Patent No. 119,950, Hiromu Tanaka, April 9, 1937) was believed by Nippon Keikinzoku, K.K.'s, engineers, after much experimental work, to be the most reliable one for extracting alumina from alunite. Over-all economy of the process appeared questionable, and wide application seemed improbable owing to excessive consumption of caustic soda. To produce 1 ton of alumina required 1.0-1.2 tons caustic soda, 4.0-4.8 tons of alunite concentrate (34 percent $Al_2O_3$), 1,800 cubic meters of producer gas, 6-18 tons steam, and 350 kw.-hr. of power. The value of the byproducts of potassium sulfate and Glauber's salt were not known.

The Sumitomo's Niihama works produced about 1,650 tons of alumina by a sulfuric acid process during 1936-37 from Korean and later from Izu alunite. The plant capacity was 5 tons alumina daily, and the cost was approximately three times that for alumina from bauxite by the Bayer process. Ammonia losses were said to be excessive, and the desilication of pregnant liquor difficult.

Asada Kogaku Kogyo's Shikama plant has produced a small tonnage of alumina yearly since 1935, aggregating 7,628 metric tons. The acid process for recovering alumina from alunite was said to have won the prize of "des Arts et des Techniques" at the 1937 Exposition Internationale in Paris. Figure 13 is a flow sheet of the acid process showing approximate quantities of materials and products per metric ton of alumina. The chemical analyses are shown in table 10.

## Process for Aluminous Phosphate Rock

Nittoh Kagaku Kogyo, K.K., at Hachinohe, Aomori Prefecture, Honshu, operated a plant on aluminum phosphate obtained from a deposit on Kitadaito Island in the Ryukyu Islands. Sulfuric acid and ammonia were used in the process. Alumina was produced as a byproduct in the manufacture of phosphate fertilizer. An aggregate of 1,085 tons of byproduct alumina was produced up to midyear 1945. Only meager details of the operation were obtained.

## Processes for Clay

As last resorts, several methods for producing alumina from domestic clays were undertaken. Clays used contained 25 to 40 percent available alumina, 25 percent silica, and 10 percent iron oxide.

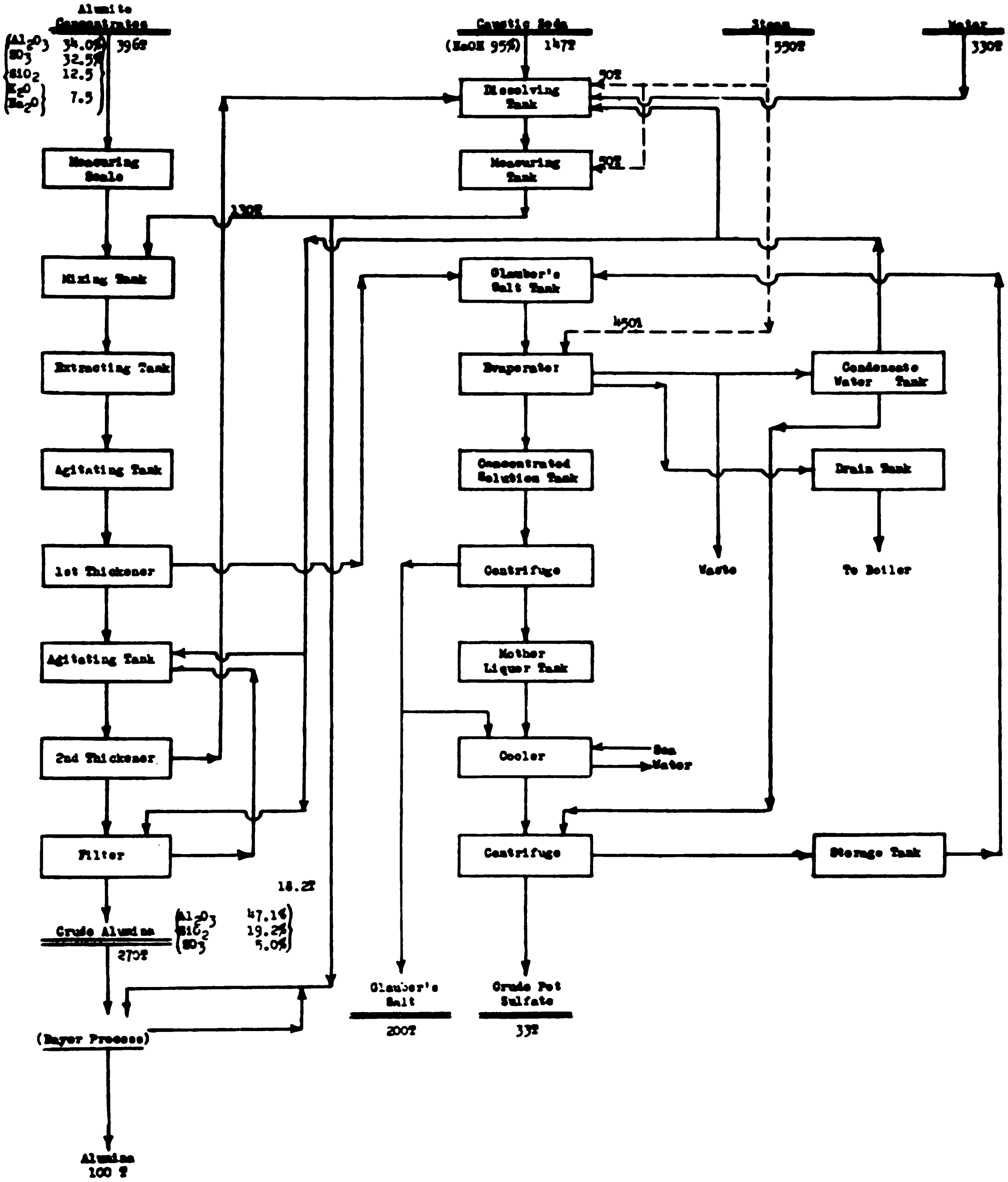
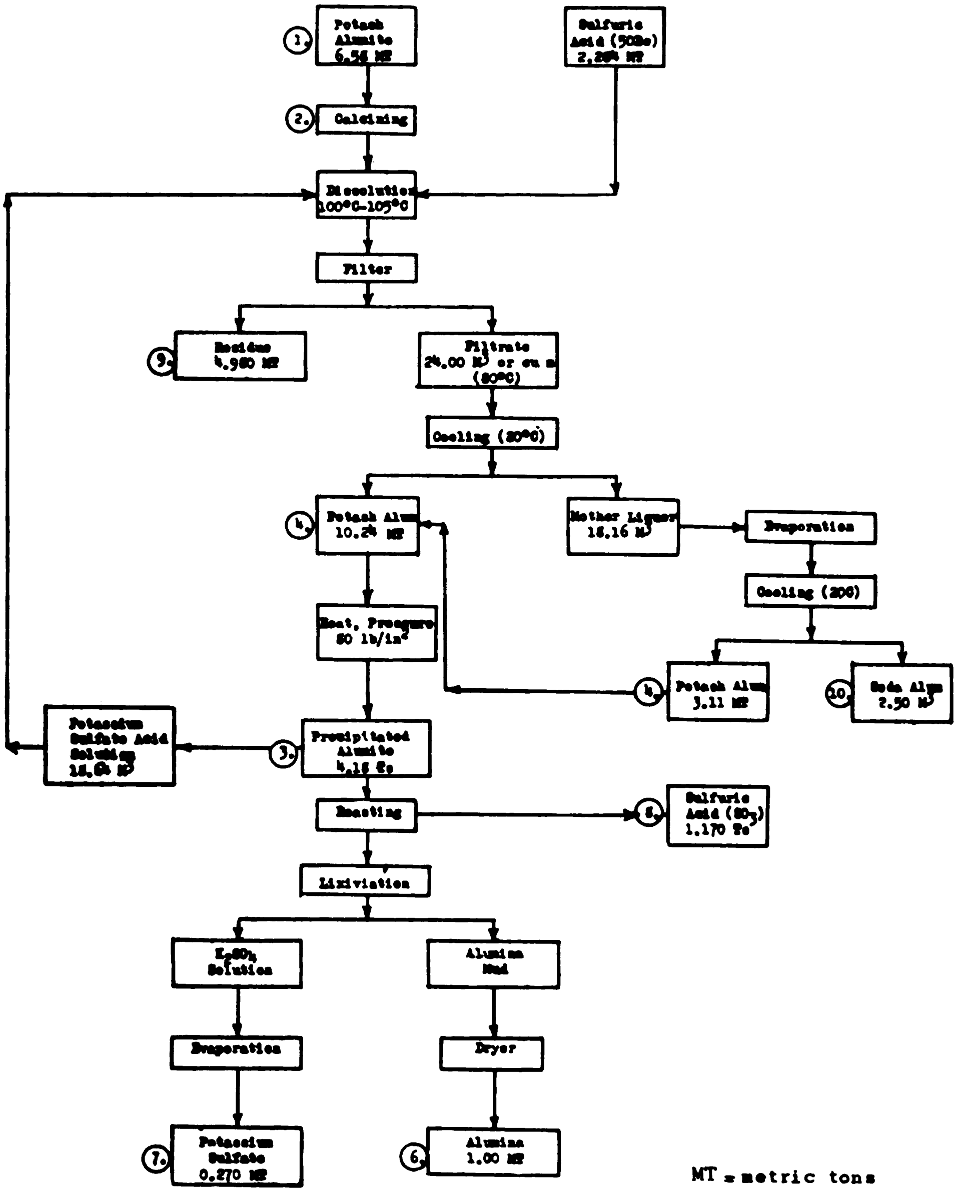


Figure 12. - Flow sheet for Tanaka process for alunite.



MT = metric tons
$M^3$ = Cubic meters
Ts = Tons

NOTE: Numbers refer to analyses in Table 10
SOURCE: Asada Kagaku Kogyo, KK

NATURAL RESOURCES SECTION GHQ SCAP

Figure 13. - Flow sheet of acid process for alumina from alunite, Asada Kagaku Kogyo, K. K.

TABLE 10. - Products of acid method of making alumina from alunite (Asada Kagaku Kogyo, K.K.)

| Acid process (flow sheet, fig. 13) | | | Description of product | Unit percent or g/1 | $H_2O$ | $SiO_2$ | $Fe_2O_3$ | CaO | $Al_2O_3$ | $K_2O$ | $Na_2O$ | $SO_3$ | $K_2SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. on flow sheet | Per 1.0 MT $Al_2O_3$ | | | | | | | | | | | | |
| | M3 | MT | | | | | | | | | | | |
| 1 .... | | 6.58 | Potash-alunite | Percent | 8.95 | 34.990 | 2.710 | 0.250 | 24.79 | 5.780 | 0.880 | 24.090 | |
| 2 .... | | 5.63 | Calcined alunite | Percent | 3.48 | 38.800 | 3.010 | 0.280 | 27.50 | 5.970 | 0.880 | 20.680 | |
| 3 .... | | 4.18 | Precipitated alunite | Percent | 33.80 | 0.024 | 0.004 | trace | 25.35 | 7.690 | 0.097 | 33.800 | |
| 4 .... | | 13.35 | Potash alum | Percent | | 0.005 | 0.001 | trace | | | | | |
| 5 .... | 18.64 | | Potassium sulfate acid sol. | g/1 | | 0.080 | 0.100 | trace | 15.55 | 48.250 | trace | 100.500 | |
| 6 .... | | 1.00 | Aluminia | Percent | 0.12 | 0.100 | 0.028 | 0.003 | 99.65 | 0.078 | | 0.025 | |
| 7 .... | | 0.27 | Potassium sulfate | Percent | | | | | | | | | 98.00 |
| 8 .... | | 1.17 | Sulfuric acid | Percent | | | | | | | | 98.000 | |
| 9 .... | | 4.98 | Residue | Percent | 43.10 | 42.900 | 3.130 | 0.210 | 5.71 | 1.020 | 0.160 | 3.710 | |
| 10[1] ... | 2.50 | | Soda alum | g/1 | | | | | | | | | |

[1] Contains 279 g/1 $Na_2SO_4.Al_2(SO_4)_3.24H_2O$.

A large plant at Kawasaki, near Yokohama, was almost completed at the end of World War II. Its theoretical capacity was 12,000 tons annually, but so far as can be ascertained it was credited with 64 metric tons of alumina, probably from pilot-plant operations. Hydrochloric acid was the proposed solvent. Much of the equipment appeared never to have been used.

A plant based on the use of sulfur dioxide with clay was operated during 1941 and produced 289 metric tons of alumina. This plant, with design capacity of 1,400 metric tons annually, was operated by Kokusen Keigin, K.K., at Iwate, Iwate Prefecture, on nearby Fukubando clay containing about 25 percent $Al_2O_3$. The plant attempted the use of sulfuric-acid process, but the supply of ammonia failed, so efforts were directed toward the use of sulfurous acid process in 1943. Dr. Hiroshi Tanaka directed the laboratory, which gave promise of successful translation to industrial-scale operation. Many changes in flow sheet and equipment consumed operating time to the extent that nothing approaching continuous operation was attained. The plant was heavily damaged by bombing, and operations were suspended.

Sumitomo Kagaku Kogyo, K.K., had a 2,000-metric ton rated annual capacity plant under construction in 1944, at Takihara, Shikoku, to treat clay by a sulfuric acid process. The experimental work was mostly on a laboratory scale, although some phases of the process were tested in an improvised pilot plant. Clay was digested with dilute sulfuric acid at 100° C. for 2 hours. The aluminum sulfate solution was separated from the insoluble residue and slowly neutralized with milk of lime at ordinary temperatures to precipitate alumina trihydrate and calcium sulfate.

The mixed precipitate was treated by flotation to separate the calcium sulfate from the alumina trihydrate. The crude alumina trihydrate was filtered and sent to a Bayer plant for further treatment.

## ALUMINUM PRODUCTION

Japan has four aluminum reduction works fully integrated with alumina, electrode, cryolite, and other auxiliary plants, which account for 60 percent of Japanese Home Islands' reduction capacity. These are Kambara, Niihama, Takaoka, and Toyama. A fifth company, Showa Denko, K.K., manufactured alumina at economically situated plants in Yokohama and Toyama and shipped alumina to reduction works in areas of low-cost electric energy. The Toyama works had its own facilities for producing alumina by the electric fusion method and for making its electrodes.

The rated annual capacity and largest production year of aluminum reduction works in Japanese Home Islands in 1946 is shown in table 11. The rated annual capacity and largest production year of aluminum reduction works in Korea, Formosa, and Manchuria are given in table 12. The yearly aluminum production in the Japanese Home Islands for 1933-45 and for the former Japanese Empire are shown in tables 13 and 14.

TABLE 11. - Rated annual capacity of aluminum reduction works in Japanese Home Islands in 1946

| Company | Plant and location, Shi Prefecture | Annual capacity M. T. | Largest production | Year | Remarks |
|---|---|---|---|---|---|
| Nippon Keikinsoku, K.K. .......... | Kambara1/2/<br>Kambara, Shizuoka | 36,000 | 34,604 | | |
| Nippon Keikinzoku, K.K. .......... | Niigata1/<br>Niigata, Niigata | 18,000 | 19,284 | 1943 | |
| Nippon Soda, K.K. ................ | Takaoka2/<br>Takaoka, Toyama | 12,000 | 10,390 | 1943 | |
| Showa Denko, K.K. ................ | Kitakata1/<br>Kitakata, Fukushima | 4,500 | 5,061 | 1944 | Original capacity 9,000; one-half of plant out of commission. |
| Showa Denko, K.K. ................ | Omachi<br>Omachi, Nagano | 22,000 | 21,655 | 1943 | |
| Showa Denko, K.K. ................ | Toyama2/<br>Toyama, Toyama | 7,000 | 5,834 | 1943 | |
| Sumitomo Aluminum Seiren, K.K. ... | Niihama1/2/<br>Niihama, Ehime | 15,000 | 18,668 | 1943 | Original capacity 25,000; section 3 damaged. |
| Tohoku Shinko Aluminum, K.K. ..... | Koriyama<br>Koriyama, Fukushima | | 3,456 | 1943 | Plant dismantled; rated capacity was 4,000. |
| Kokusan Keigin, K.K. ............. | Osawano<br>Osawano, Toyama | 1,200 | None | | |
| Total ........................ | | 115,700 | 114,206 | | |

1/ Plants producing secondary aluminum in September 1946.
2/ Reduction works integrated with alumina, electrode, cryolite, and other auxilliary plants.
Source: Light Metal Control Association reports with revision to date of some plant annual capacities as result of plant inspection of G. L. Allen, Natural Resources Section.

TABLE 12. - Rated annual capacity of aluminum reduction works, Korea, Formosa, Manchuria

| Company | Plant and location, Shi Prefecture | Annual capacity M. T. | Largest production | Year | Remarks |
|---|---|---|---|---|---|
| Korea ........................ |  | 30,960 | 12,943 | 1944 |  |
| Chosen Keikinzoku, K.K. ... | Chosen Chinnanpo, Korea[3] | 3,500 | 3,579 | 1943 |  |
| Mitsui Keikinzoku, K.K. ... | Yoshi, Korea | 21,460 | 6,009 | 1944 | Formerly Toyo Keikinzoku, K.K. |
| Nippon Chisso Hiryo, K.K... | Konan[3]<br>Konan, Korea | 6,000 | 4,096 | 1944 |  |
| Chosen Sumitomo Keikinzoku, K.K. ......... | Genzan<br>Genzan, Korea | (8,000) |  |  | Under construction at war's end. |
| Chosen Denko, K.K. ........ | Chosen Denko<br>Chinnanpo | (50,000) |  |  | Under construction in 1945. |
| Formosa ...................... |  | 12,000 | 14,498 | 1943 |  |
| Nippon Aluminum, K.K. ..... | Karenko<br>Karenko, Formosa | [1](8,000) | 3,813 | 1943 | Almost totally destroyed. |
| Nippon Aluminum, K.K. ..... | Takao[3]<br>Takao, Formosa | 12,000 | 12,083 | 1942 |  |
| Manchuria .................... |  | 10,000 | 8,557 | 1943 | Additional 5,000 tons plant nearly completed August 1945. |
| Manchu Keikinzoku, K.K. ... | Fushun[3]<br>Fushun, Manchuria | [2]10,000 | 8,557 |  |  |
| Anto Keikinzoku, K.K. ..... | Antung, Antung, Manchuria | (10,000) |  |  | Planned to reduce $Al_2O_3$. |

[1] Capacities in parenthesis were for plants under construction, planned or destroyed.

[2] Aluminum plant reported completely inoperable in September 1946 as result of Russian removals of equipment and removal of six of the eight generators in the Fushun hydroelectric plant (Report by Victory Keen, correspondent, New York News, who visited Manchuria in midyear 1946).

[3] Reduction works having alumina plants.

Source: Light Metals Control Association, company reports, Economic and Scientific Section Report No. 9, April 1946, The Aluminum Industry of Japan, Part I.

TABLE 13. - Aluminum production in Japanese Home Islands, 1933-45, metric tons

| Company | Location | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 |
|---|---|---|---|---|---|---|---|---|
| Nippon Keikinzoku (Kambara)....... | Kambara, Shizuoka Pref. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nippon Keikinzoku (Niigata) ...... | Niigata, Niigata Pref. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nippon Soda Co. (Takaoka) ........ | Takaoka, Toyama Pref. | 0 | 0 | 0 | 0 | 953 | 2,753 | 4,413 |
| Showa Denko Co. (Kitakata) ....... | Kitakata, Fukushima Pref. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Showa Denko Co. (Omachi) ......... | Omachi, Nagano Pref. | 19 | 1,002 | 2,997 | 3,533 | 6,168 | 8,995 | 9,464 |
| Showa Denko Co. (Toyama)2/ ....... | Toyama, Toyama Pref. | 0 | 0 | 214 | 1,187 | 3,471 | 3,517 | 3,289 |
| Sumitomo Aluminum Seiren Co., Ltd. | Niihama, Ehime Pref. | 0 | 0 | 0 | 872 | 1,066 | 2,494 | 3,113 |
| Tohoku Shinko Aluminum Co., Ltd. . | Koriyama, Fukushima Pref. | 0 | 0 | 0 | 0 | 0 | 0 | 1,379 |
| Kokusan Keigin, K.K.3/ ........... | Osawano, Toyama Pref. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total ........................ |  | 19 | 1,002 | 3,211 | 5,592 | 11,658 | 17,759 | 21,658 |

| Company | Location | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 1/ | Total |
|---|---|---|---|---|---|---|---|---|
| Nippon Keikinzoku (Kambara) ...... | Kambara, Shizuoka Pref. | 2,024 | 10,216 | 16,524 | 34,604 | 24,793 | 1,709 | 89,870 |
| Nippon Keikinzoku (Niigata) ...... | Niigata, Niigata Pref. | 217 | 6,880 | 14,739 | 19,284 | 12,844 | 200 | 54,164 |
| Nippon Soda Co. (Takaoka) ........ | Takaoka, Toyama Pref. | 5,090 | 5,418 | 9,119 | 10,390 | 8,723 | 349 | 47,208 |
| Showa Denko Co. (Kitakata) ....... | Kitakata, Fukushima Pref. | 0 | 0 | 0 | 166 | 5,061 | 765 | 5,992 |
| Showa Denko Co. (Omachi) ......... | Omachi, Nagano Pref. | 10,233 | 16,276 | 19,685 | 21,655 | 13,740 | 439 | 114,206 |
| Showa Denko Co. (Toyama)2/ ....... | Toyama, Toyama Pref. | 3,713 | 3,829 | 5,531 | 5,834 | 5,304 | 987 | 36,876 |
| Sumitomo Aluminum Seiren Co., Ltd. | Niihama, Ehime Pref. | 6,971 | 11,453 | 16,443 | 18,668 | 15,421 | 955 | 77,456 |
| Tohoku Shinko Aluminum Co., Ltd. . | Koriyama, Fukushima Pref. | 2,372 | 2,008 | 3,170 | 3,456 | 2,368 | 0 | 14,753 |
| Kokusan Keigin, K.K.3/ ........... | Osawano, Toyama Pref. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total ........................ |  | 30,620 | 56,080 | 85,211 | 114,057 | 88,254 | 5,404 | 440,525 |

1/ April 1 to June 30, inclusive.
2/ 1935-1942 Nichiman Aluminum Co., bought by Showa Denko Co., Ltd. (Toyama).
3/ Kokusan Keigin, Kabushiki Kaisha, no production.
Source: Natural Resources Report No. 44, Mineral Resources of Japan proper, 1925-1945.

TABLE 14. - Aluminum production in the former Japanese Empire, 1933-45, metric tons

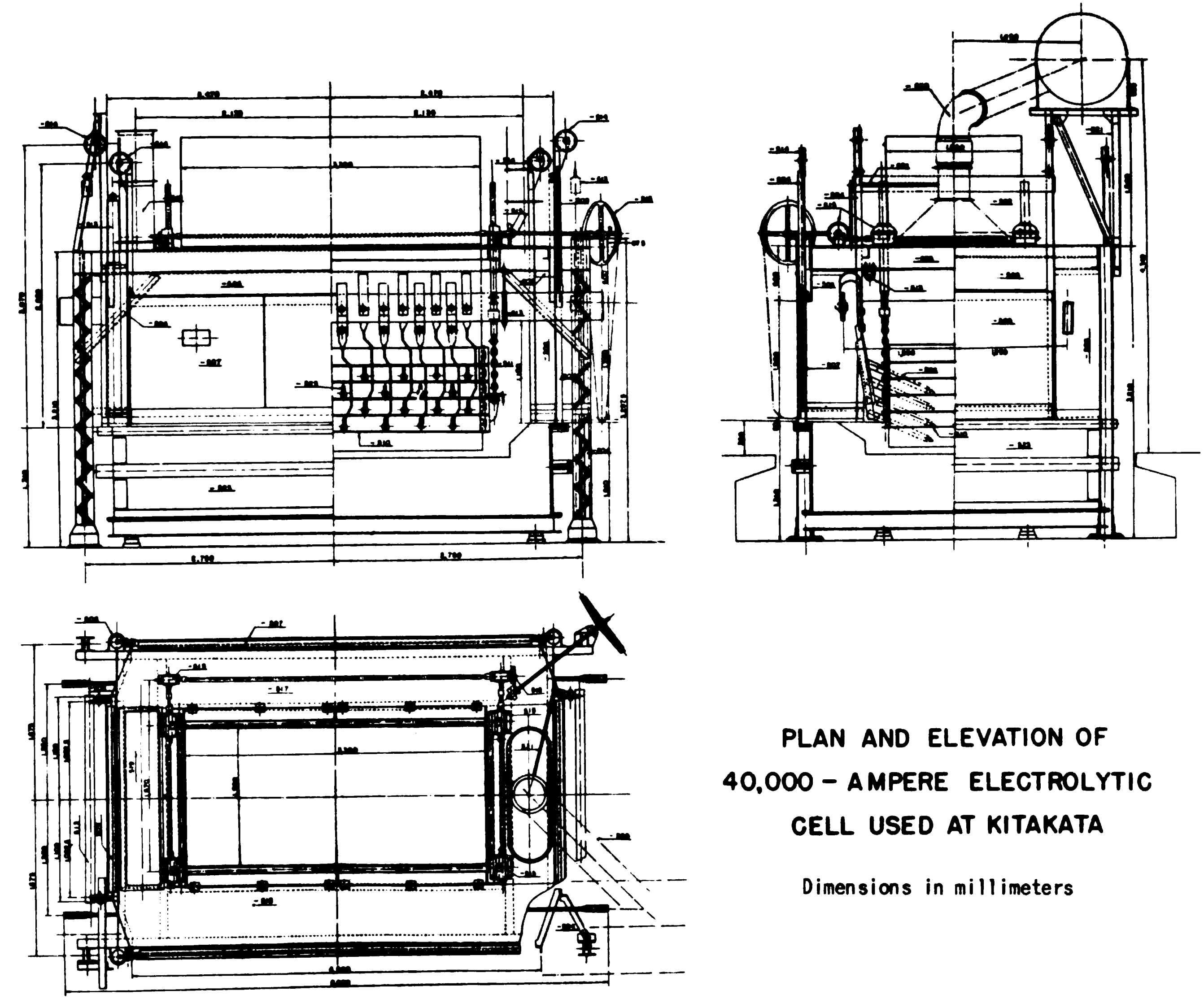
| Year | Home Islands | Korea | Formosa | Manchuria | Total |
|---|---|---|---|---|---|
| 1933 ......... | 19 | 0 | 0 | 0 | 19 |
| 1934 ......... | 1,002 | 0 | 0 | 0 | 1,002 |
| 1935 ......... | 3,211 | 0 | 0 | 0 | 3,211 |
| 1936 ......... | 5,592 | 0 | 210 | 0 | 5,802 |
| 1937 ......... | 11,658 | 0 | 2,776 | 0 | 14,434 |
| 1938 ......... | 17,759 | 0 | 4,608 | 952 | 23,319 |
| 1939 ......... | 21,658 | 240 | 7,661 | 3,258 | 32,817 |
| 1940 ......... | 30,620 | 1,481 | 8,762 | 5,026 | 45,889 |
| 1941 ......... | 56,080 | 3,120 | 12,547 | 8,032 | 79,779 |
| 1942 ......... | 85,211 | 4,366 | 13,498 | 7,437 | 110,512 |
| 1943 ......... | 114,057 | 12,529 | 14,498 | 8,557 | 149,641 |
| 1944 ......... | 88,254 | 12,943 | 9,201 | 2/8,000 | 118,398 |
| 1945 1/........ | 5,404 | 1,243 | 0 | 2/1,500 | 8,147 |
| Total ... | 440,525 | 35,922 | 73,761 | 42,762 | 592,970 |

1/ April 1 to June 30, inclusive.
2/ Estimated by Japan Mining Bureau.
Source: Natural Resources Section Report No. 44, Mineral Resources of Japan proper, 1925-1945.

## Reduction Process (Hall-Heroult)

In Japan, as in other great aluminum-producing countries, the Hall-Heroult electrolytic process is almost universally employed as the second step in the production of aluminum from aluminous material. The process is based on the discovery that alumina dissolves in a molten solution of sodium, calcium, and aluminum fluorides, and that under the influence of the electric current the alumina dissociates into aluminum and oxygen. The composition and temperature of the molten bath of fused fluorides are so maintained that the specific gravity of the bath (about 2.08) at the operating temperature of the cell is lower than that of aluminum (2.3 sp. gr. at 900° C.); therefore, the metal aluminum, after electrolytic dissociation from the oxygen of the alumina, sinks to the cathode at the bottom of the cell (furnace) and is periodically tapped off. The oxygen migrates to the carbon anode at the top of the bath, combines with the carbon anode to form carbon monoxide, which unites with air to make carbon dioxide and is drawn off to scrubbers along with other furnace gases and dust. The bath is not appreciably affected by the same current. In practice, however, some of the valuable fluorine of the cryolite bath is volatilized and drawn off to the scrubbers (along with other furnace gases), where part of it is recovered, converted into cryolite, and returned to the process for reuse.

Features of aluminum reduction include the almost universal practice in Japan of adding aluminum fluoride to the bath in the electrolysis, about 0.03 ton per ton of aluminum produced; the tendency in Japan is toward the use of electrolytic cells carrying amperages up to 40,000. The use of the Soederberg continuous electrode is generally standard practice. All cells in Japan proper taking more than 20,000 ampere lines are provided with the continuous-type anode.



PLAN AND ELEVATION OF
40,000 - AMPERE ELECTROLYTIC
CELL USED AT KITAKATA

Dimensions in millimeters

NATURAL RESOURCES SECTION GHQ SCAP

Figure 14.

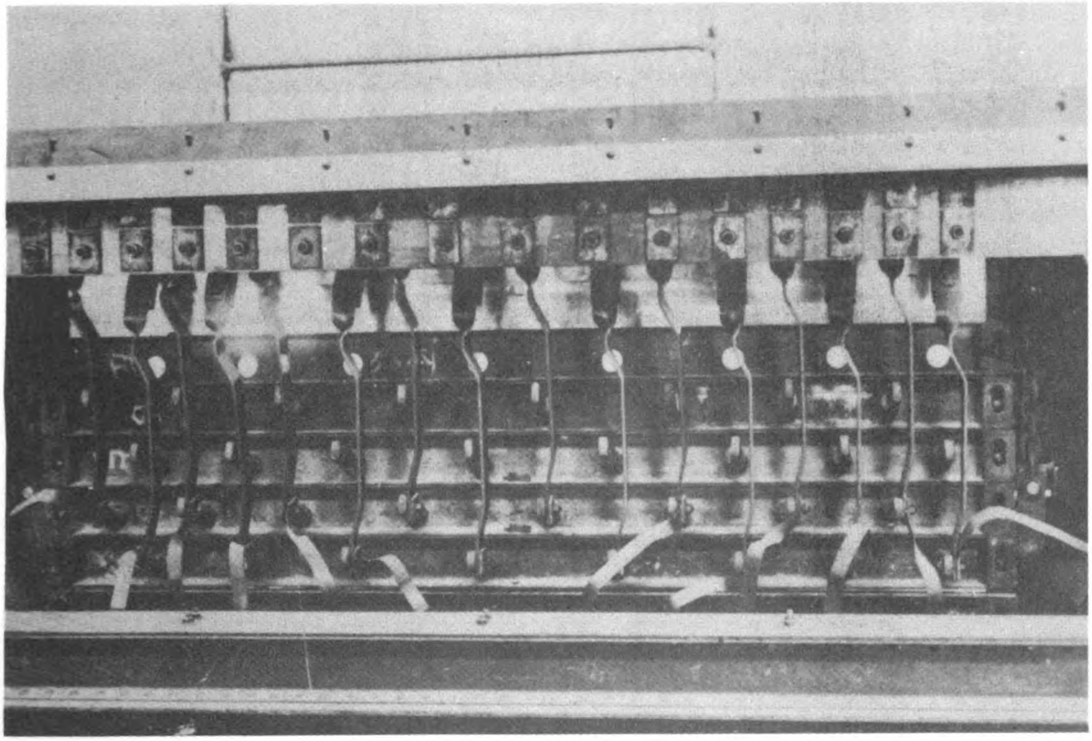


**Figure 15.** - Soederberg-anode type 40,000-ampere aluminum reduction cell, side view, showing heating pins.

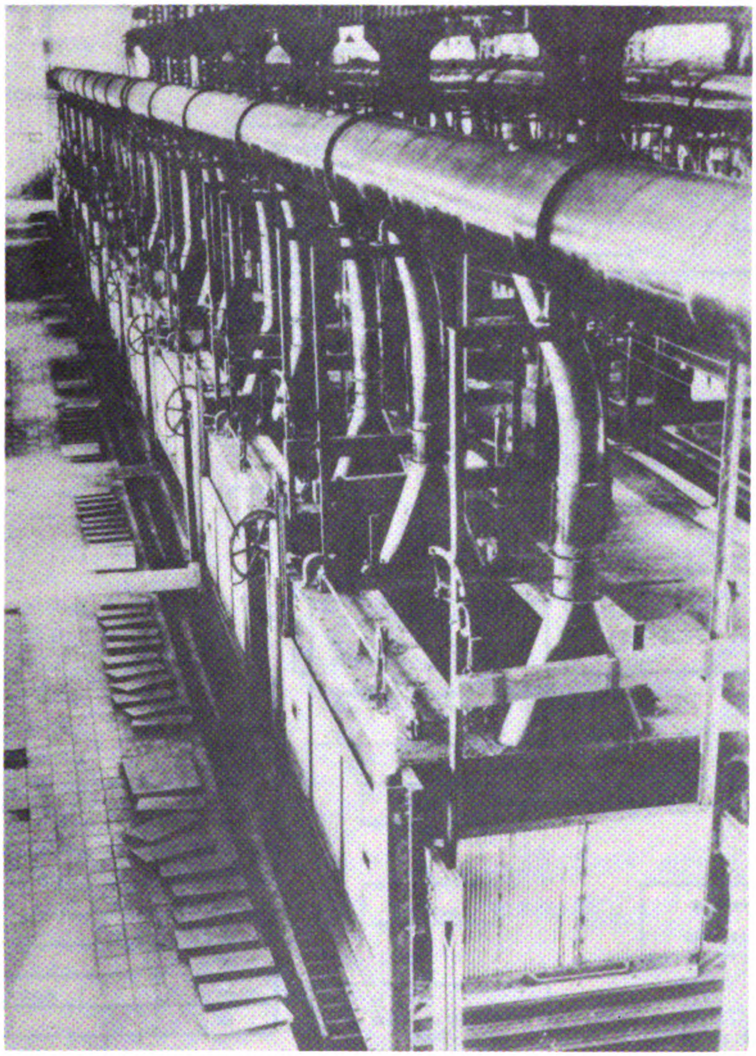
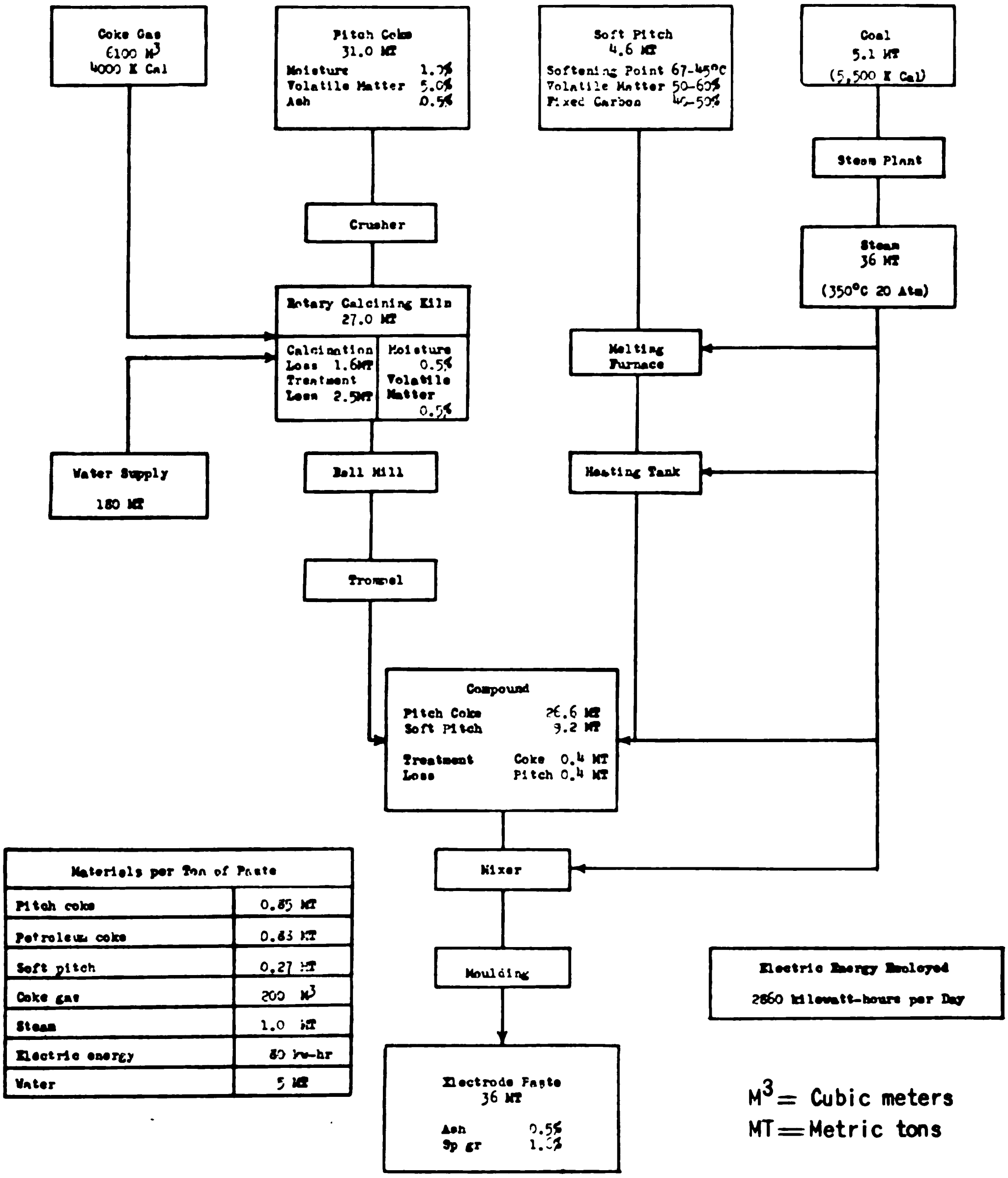


Figure 16. - Pot line Niigata reduction works.

# KUROSAKI PLANT, NIPPON ALUMINUM CO, LTD.
# 36 MT/DAY 12,000 MT/YR.



| Materials per Ton of Paste | |
|---|---|
| Pitch coke | 0.85 MT |
| Petroleum coke | 0.83 MT |
| Soft pitch | 0.27 MT |
| Coke gas | 200 M3 |
| Steam | 1.0 MT |
| Electric energy | 80 kw-hr |
| Water | 5 MT |

NATURAL RESOURCES SECTION GHQ SCAP

Figure 17. - Flow sheet of paste manufacturing plant.

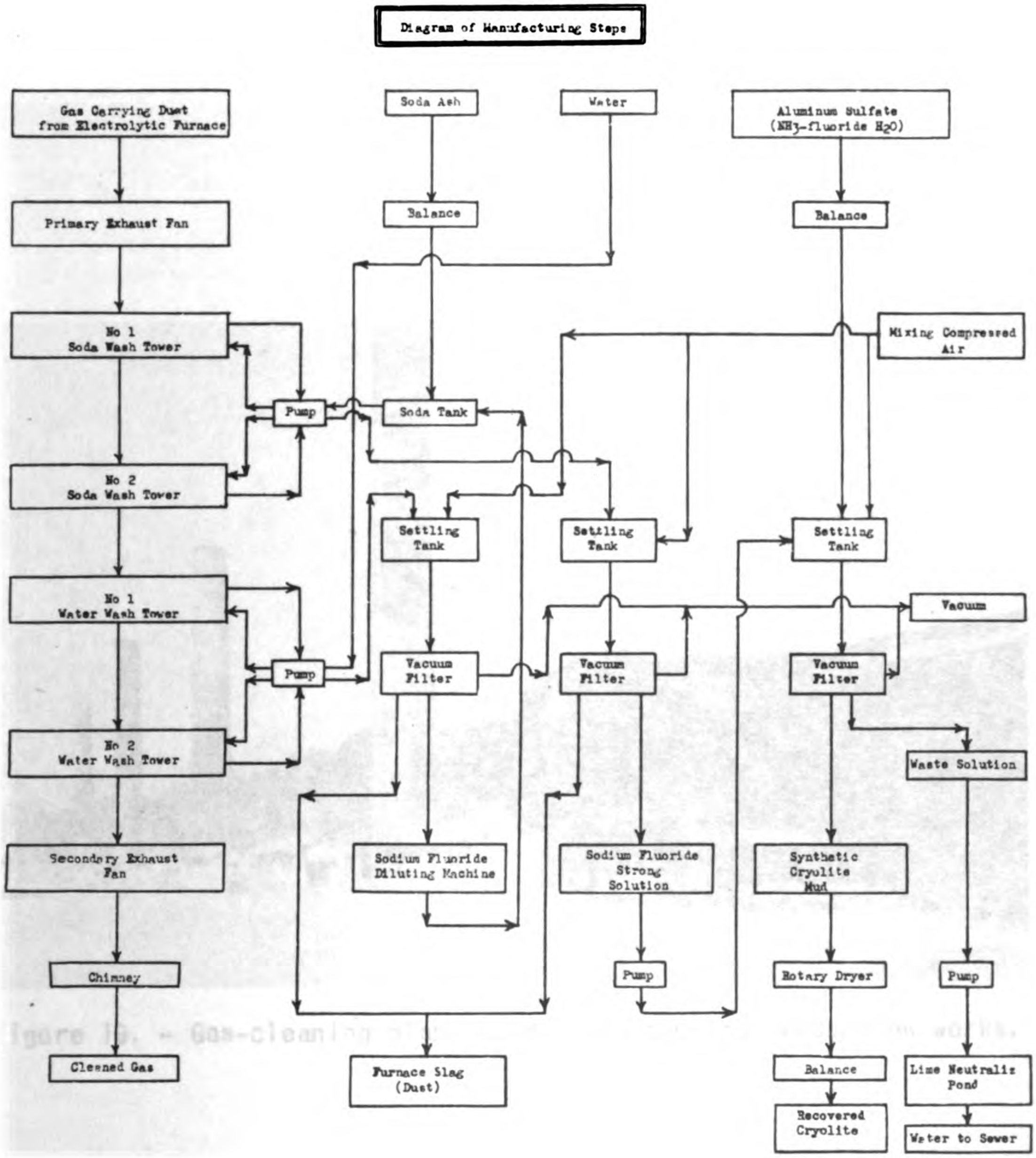


Figure 18. - Flow sheet for gas-treating plant Niigata aluminum reduction works, Nippon Keikinzoku, K. K.

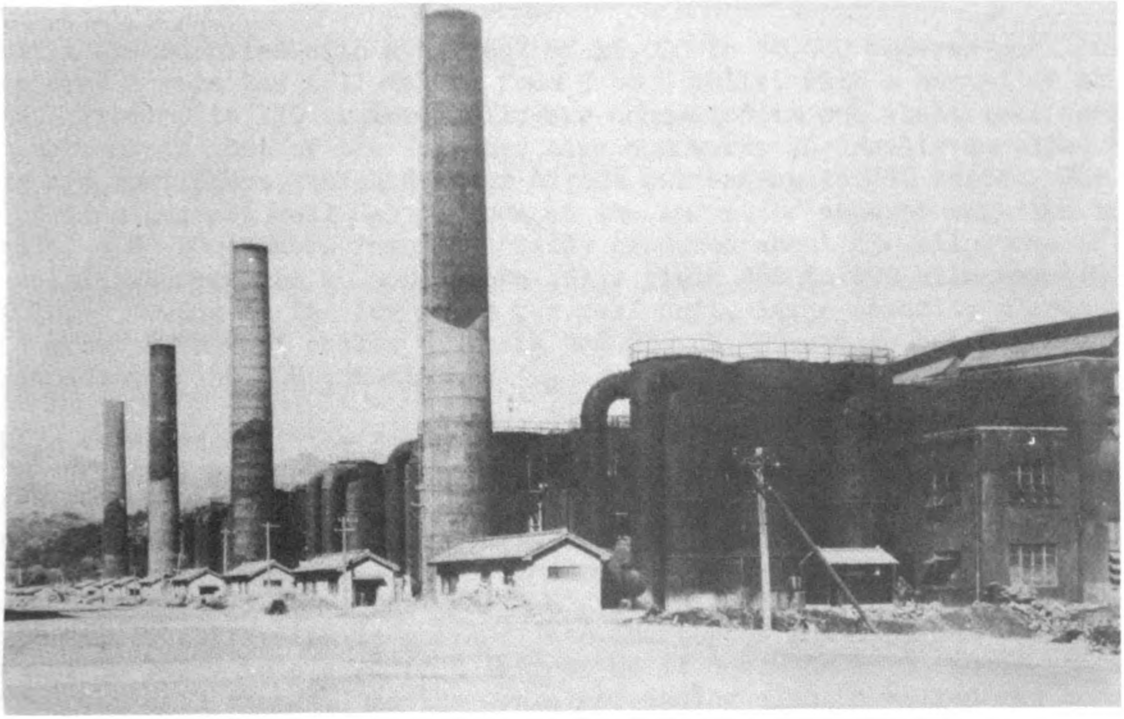


Figure 19. - Gas-cleaning plant at Niigata aluminum reduction works.

Hall-Heroult electrolytic furnaces for production of aluminum consist generally of an open-top, shallow, rectangular tank of steel plate lined with a thick layer of nonconducting refractory material. On top of the refractory lining is a lining of carbon, which serves as the cathode. This lining is connected to the electric circuit through a metal cathode plate imbedded in the carbon cell-bottom liner.

In the solid-anode type of furnace, carbon anodes having round or square cross-sections are adjustably suspended above the cell, so that they can be lowered gradually into the bath as the lower end of the anode is burned off and consumed in the reduction process. After the electrolyte bath has been built up to operating requirements, the cells are charged with finely powdered alumina at intervals of a few hours; metal is tapped off the bottom of the cell every 48 to 72 hours.

Cells are supplied with a current of 15,000 to 40,000 amperes per line. Voltage drop across the cell varies from 5 to 8 volts, with a normal of about 6 volts. From 60 to 130 or more cells are connected in one electrical series. Direct current in most of the Japanese aluminum works is usually supplied by mercury arc rectifiers, which deliver direct current up to 760 volts. The yield of aluminum per cell day depends on the amount of amperes supplied to the cells; a 20,000-ampere furnace usually produces about 130 kilograms of metal daily, whereas the 40,000-ampere cells yield 260 to 270 kilograms (570 to 590 lb.). Owing to the low yield per cell unit, large-capacity plants require a great number of cells. Kambara had 538 32,000-ampere cells for a rated capacity of 36,000 annual tons.

Wide acceptance of the Soederberg continuously formed self-baking electrode in Japanese aluminum practice and the tendency toward cells of high amperage and high yield have been mentioned. The electrode used in Japan consists of a rectangular sheet-aluminum casing, open at top and bottom, almost as large in horizontal cross section as the top of the furnace proper and suspended movably above the cell. A semifluid mixture of carbon or pitch coke and tar or soft pitch is charged into the top of the aluminum casing or sleeve and is baked into a solid electrode as it descends into and is consumed in the molten cell charge. As the container casing also is melted and consumed in the molten bath, it must be renewed at the top end from time to time by welding on new sections as needed. The paste is partly supported in the casing by heating pins, which enter the casing from the side. Plan, side, and end elevations of the Soederberg 40,000-ampere cell used at the Kitakata works of Showa Denko, K.K., are illustrated in figure 14. A photograph of a side view of a typical Soederberg reduction cell is shown in figure 15. A photograph of the pot line at the Niigata reduction works is shown in figure 16. Advantages claimed for the Soederberg electrode include greater convenience in supplying the furnace with electrode and higher recovery of fluorine gas. Flow sheet of a typical paste manufacturing plant is shown in figure 17. Consumption of paste, anode carbon, and other furnace requirements per metric ton of aluminum are given in table 15. Direct operating costs per metric ton of aluminum in yen and distribution of costs in percent for the year 1942 are shown in table 16. A typical flow sheet for the recovery of fluorine gas is shown in figure 18. A photograph of the gas-cleaning plant at Niigata aluminum reduction works is shown in figure 19.

TABLE 15. - Tons of raw materials required per ton of aluminum

| Material, metric tons per ton aluminum | Average Japanese consumption, includes manufacturing 2 tons $Al_2O_3$ | Al only |  |  |  | Al from dross, Niigata | Electric fusion, includes $Al_2O_3$, Toyama | Calcium aluminate, includes 2 tons $Al_2O_3$, Fushun |
|---|---|---|---|---|---|---|---|---|
|  |  | Kitakata, March 1945 | Niihama | Nambara | Niigata |  |  |  |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Dross | | | | | | 2.170 | | |
| Bauxite | 4.60 | | 2/4.90 | | | | 0.060 | |
| Alumina | | 2.320 | | 2.050 | 3/2.358 | | 1.815 | |
| Coal | 4.00 | | 4.10 | | | | | 4.195 |
| Anthracite | | | 1.80 | | | | 1.700 | |
| Petroleum or pitch coke | 0.80 | | 0.60 | | 0.610 | | | |
| Anode paste | | 0.861 | | | | 0.705 | | 4/0.738 |
| Soft pitch | 0.20 | | 0.21 | | 0.067 | | | 5/0.459 |
| Anode carbon | | | | 0.650 | | | 6/1.713 | |
| Soda ash | 0.20 | | | | | | | 1.006 |
| Caustic soda | | | 0.24 | | | | | |
| Lime or limestone | 0.35 | | | | | | | 7/6.312 |
| Cryolite | 0.12 | 0.135 | 0.15 | 0.100 | 0.112 | 0.420 | 0.150-0.220 | 8/0.367 |
| Aluminous shale | | | | | | | | 7.430 |
| Scrap iron | | | | | | | 0.624 | 1.564 |
| Aluminum fluoride | 0.03 | 0.054 | 0.03 | 0.020 | 0.017 | 0.250 | 0.026 | |
| Sulfuric acid | | | | | | | 0.090 | 0.510 |
| Power, kw.hr./ton | 24,000 | 21,453 | | | 20,832 | 34,855 | 9/57,470 | 9/52,115 |
| Coke | | | | | | | | 3.526 |

1/ Columns 1, 3, and 8 include materials for 2 tons $Al_2O_3$; columns 7 and 8 include materials for 2 tons $Al_2O_3$ and 2 tons FeSiAl; column 1 actual Japanese average by Tiedemann.

2/ Column 3, 53.70% $Al_2O_3$; 13.50% $Fe_2O_3$; 2.70% $SiO_2$; 0.95% $TiO_2$; 29.00% LOI.

3/ Column 5, 1.840% $H_2O$; 1.920% LOI; 96.71% $Al_2O_3$; 0.066% $Fe_2O_3$; 0.110% $SiO_2$; 0.009% $TiO_2$; 0.820% $Na_2O$.

4/ Column 8, shale coke used in anode paste.

5/ Column 8, tar for fuel.

6/ Column 7, includes 0.770 ton electrode for alumina furnace, 0.943 for electrolysis.

7/ Column 8, limestone.

8/ Column 8, fluorspar.

9/ Columns 7 and 8, includes power for producing 1.8 to 2 tons $Al_2O_3$ and 2 tons ferrosilicon byproduct.

Source: Company reports on plants listed in column headings.

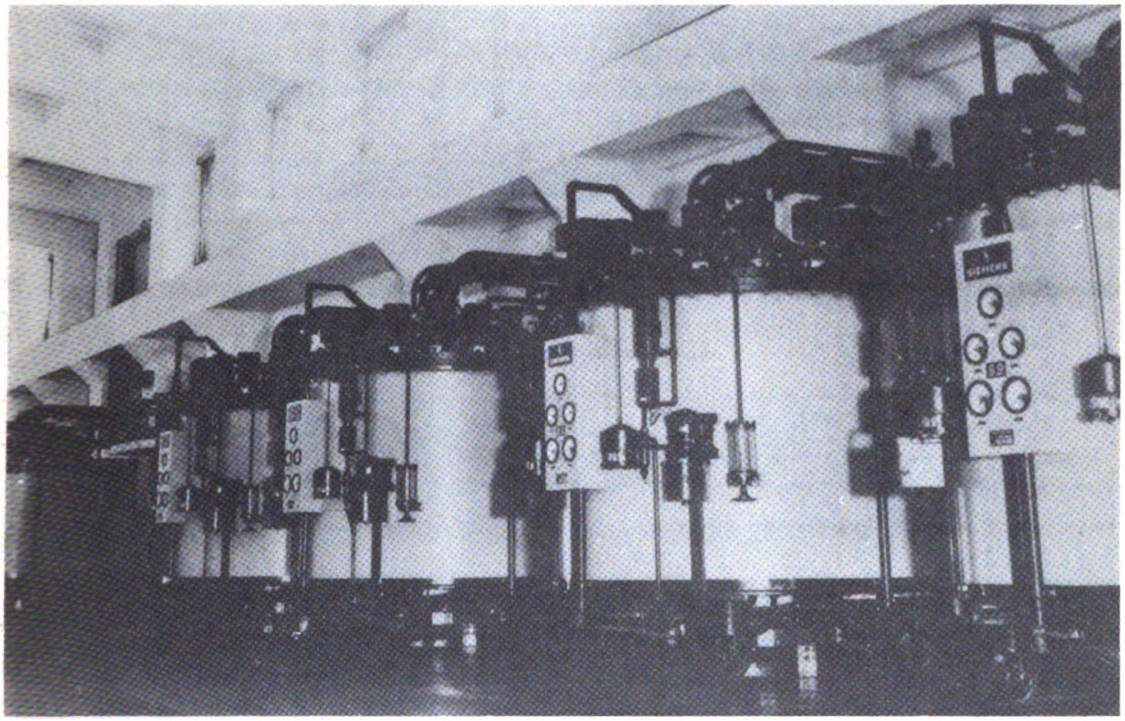


Figure 20. - Rectifier installation Japanese aluminum reduction works.

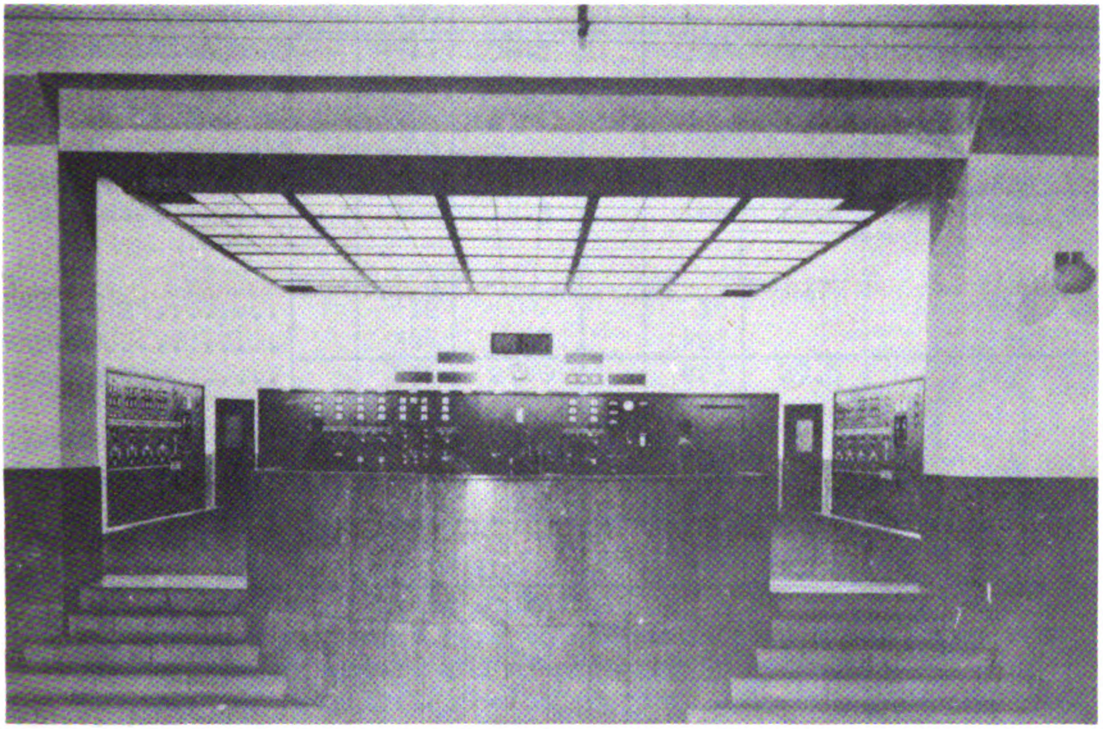


Figure 21. - Distributing room in rectifier plant.

TABLE 16. - Direct operating costs, in yen, and distribution of costs, in percent, 1942

| | Nippon Keikinzoku Shimizu and Kambara works | | | Sumitomo Nishihama works | | | Showa Denko Yokohama and Kamachi reduction works | | |
|---|---|---|---|---|---|---|---|---|---|
| | Yen | Yen | Percent | Yen | Yen | Percent | Yen | Yen | Percent |
| Supplies: | | | | | | | | | |
| Alumina raw ........ | 153 | | | 153 | | | 153 | | |
| Repair and operation | 6 | | | 41 | | | 46 | | |
| Total x 2 ........ | 159 | 318 | | 194 | 388 | | 199 | 398 | |
| Alumina raw ........ | 295 | | | 295 | | | 295 | | |
| Repair and operation | 104 | 399 | | 113 | | | 114 | | |
| Total supplies ... | | 717 | 54.3 | | 796 | 55.5 | | 807 | 59.3 |
| Labor: | | | | | | | | | |
| Alumina x 2 ........ | | 48 | | | 28 | | | 52 | |
| Aluminum .......... | | 114 | | | 116 | | | 94 | |
| Total labor ...... | | 162 | 12.3 | | 144 | 10.1 | | 146 | 10.7 |
| Power: | | | | | | | | | |
| Alumina x 2 ........ | | 12 | | | 16 | | | 18 | |
| Aluminum .......... | | 344 | | | 407 | | | 331 | |
| Total power ...... | | 356 | 27.0 | | 423 | 29.5 | | 349 | 25.6 |
| Miscellaneous1/: | | | | | | | | | |
| Alumina x 2 ........ | | 0 | | | 0 | | | 0 | |
| Aluminum .......... | | 84 | 6.4 | | 70 | 4.9 | | 59 | 4.4 |
| Total per ton of aluminum .......... | | 1,319 | 100.0 | | 1,433 | 100.0 | | 1,361 | 100.0 |

1/ Costs include direct operating overhead.

Note: Data have been regrouped here to obtain subtotals for prime costs; supplies, labor, power, and miscellaneous (overhead).

Source: Economic and Scientific Section Report, July 20, 1946, The Aluminum Industry of Japan, Part III.

Electrical installations in Japanese plants generally are better equipped and maintained than the plants they serve (see photographs shown in figs. 20 and 21). Most reduction works have out-door type receiving substations. Electric resistance-type holding and remelting furnaces were used more than oil-fired reverberatories, owing to differences in cost and difficulty in obtaining oil during World War II. Smaller electric furnaces up to 5 tons capacity, were used for holding metal and serving the casting machines. Some remelting furnaces noted were 20 tons per charge capacity. A few rotary converters for producing direct current were used, but arc rectifiers, usually of German Siemen's designs (made in Japan), were preferred. Their performance was said to be highly satisfactory. Those inspected were rated at 3,000-4,500 kilowatts, 600-750 volts, and 5,000 to 6,000 amperes. The larger aluminum works were adequately provided with well-equipped laboratories for both

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control and research work. Other service departments, such as shops, warehouses, accounting, welfare, shrines, and industrial housing, were usually adequate.

## Aluminum Refining

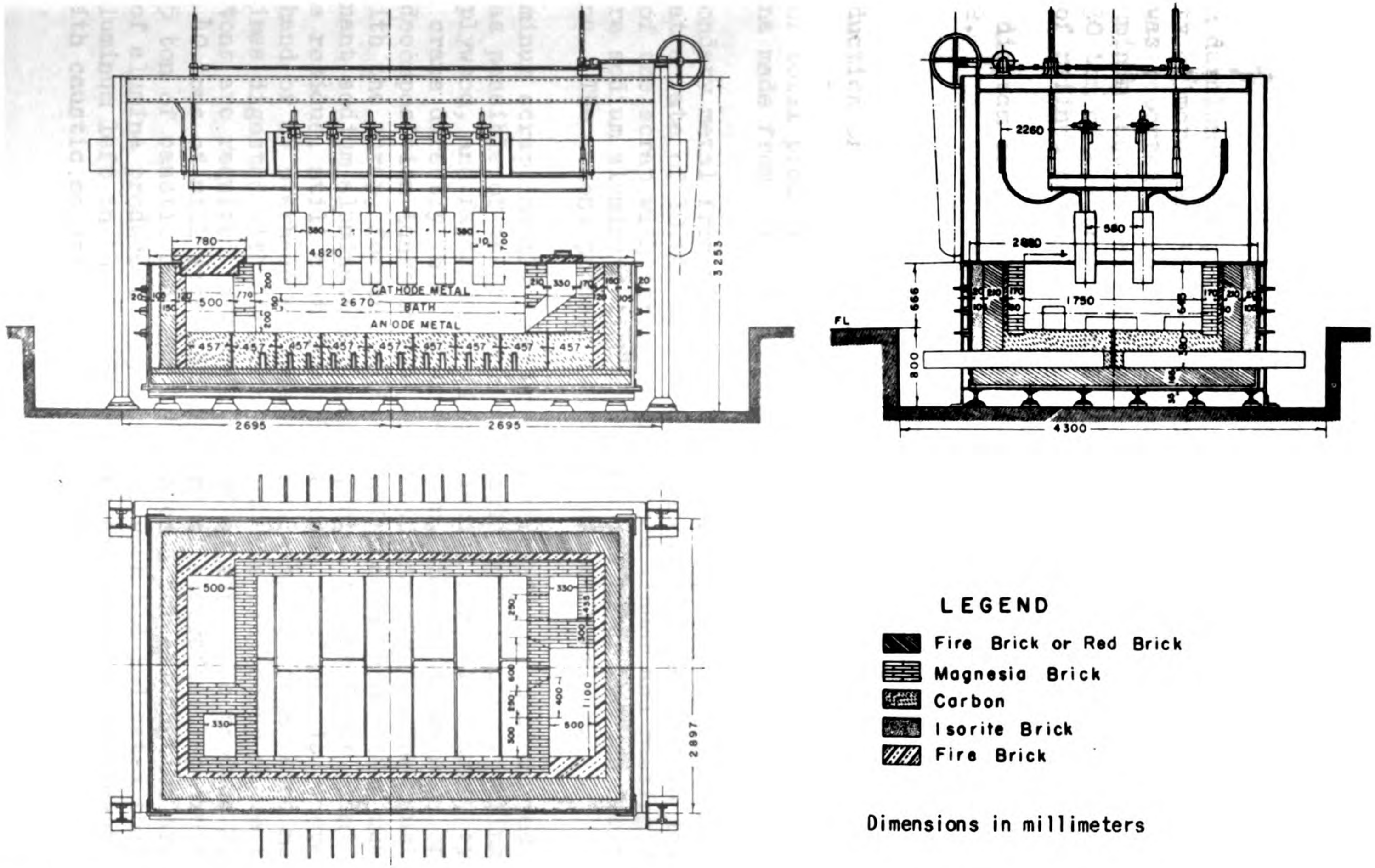
All crude aluminum was remelted to improve the purity of the final ingot metal. With good-quality Bayer alumina, all reduction plants produced aluminum with purity in excess of 99 percent. From 30 to 60 percent of the metal produced from electric fusion and calcium aluminate aluminas was lower than 99 percent. Most alumina from shale resulted in at least part of the ingot metal being substandard even after remelting.

The Japanese met their requirements of extremely high-purity metal by adopting and perfecting the use of the Hoopes (United States) patents. Sumitomo's Niihama works developed considerable skill in refining (raffination, Japanese adaptation of a German word for refining) impure metal, even duralumin scrap, in the inverted Hoope's type electrolytic cell, using a three-layer bath. The layer in the bottom of the cell is a molten copper-aluminum alloy, which serves as the anode. The middle layer is a fused cryolite-barium fluoride solution (the main bath electrolyte), and the top layer is extremely pure aluminum, which serves as the cathode. Sumitomo claims to have succeeded in producing metal of 99.99 plus purity in September 1941. Purities up to 99.88 percent can be obtained in regular operations, and up to 99.958 percent has been attained on duralumin scrap, according to company analysis. Some help in the technique may have been obtained from European practice, but the basic ideas are Hoopes. Sumitomo, after extensive effort in perfecting the practice, went into continuous industrial production of high-purity metal in 1940, using 15,000-ampere cells, as shown in figure 16. The following information was taken from the company's report on the process.

The lower part of the cell consists of a carbon bottom lining, on which rests the molten anode alloy. Superimposed upon this is the molten electrolyte, and upon this floats the molten cathode aluminum. During electrolysis, aluminum moves from the anode layer to the cathode layer. Side walls of the cell consist of fireproof materials, such as magnesia brick, and must be durable against the electrolyte and the two metal layers. The end walls have shafts extending into the anode alloy layer, through which aluminum or scrap aluminum alloy to be refined is fed.

Carbon or graphite electrodes dipping into the floating aluminum layer are used to make an electrical connection with the molten cathode. They are carried on heavy copper rods, as shown in the diagram. There seems to be only one practical anode for such a cell, a copper aluminum alloy having the density necessary to keep it on the bottom of the cell. An alloy of aluminum and copper containing about 33 percent copper has a density of about 3.0 at 800° C. and is sufficiently high to insure that the alloy will not float but will remain beneath the electrolyte.

The electrolyte is composed of a mixture of fluorides of aluminum, sodium, barium, and calcium. A suitable electrolyte may have approximately the following composition:



NATURAL RESOURCES SECTION GHQ SCAP

Figure 22. - Diagram of electrolytic refining cell, Sumitomo.

| | Percent |
|---|---|
| Aluminum fluoride .......... | 43 |
| Sodium fluoride ............ | 14 |
| Barium fluoride ............ | 30 |
| Calcium fluoride ........... | 13 |

From duralumin scrap that contained 92 percent aluminum, aluminum with the purity of more than 99.95 percent has been produced. The power for the process was reported as 24,000 kilowatt-hours per ton of refined metal. Scrap aluminum required was 135 percent of the weight of the refined metal. About 0.30 ton of electrolyte and 0.05 ton graphite electrode are consumed per ton of refined metal.

The diagram of the electrolytic refining cell, Sumitomo, is shown in figure 22.

## SECONDARY ALUMINUM PRODUCTION

Production of secondary aluminum has never attained large proportions in Japan; even during the years of World War II it represented only about 11 percent of total production. About half of the metal produced by reduction of alumina made from scrap is 97 plus percent aluminum.

Secondary metal from wrecked aircraft scrap is being produced by two methods at a rate of 10,000 metric tons annually. One process involves digestion of the scrap with strong caustic soda liquor and passing the resulting impure sodium aluminate liquor through the Bayer process for production of alumina. The second process is simply direct remelting.

Aluminum scrap, mostly from wrecked aircraft, is hand-sorted to remove as much as possible of the foreign materials such as copper tubing, hardware, fabric, plywood, and fastenings. The selected scrap is charged by hand or overhead crane directly into out-door, open, shallow tanks made of concrete or into decomposition tanks in the Bayer hydrate plant. The caustic liquor reacts with the scrap, forming sodium aluminate and generating much heat. The pregnant sodium aluminate liquor is pumped to the Bayer plant for processing. The residue, still containing 60 percent aluminum, is removed from the tank by hand or by overhead equipment. At Shimizu, accumulated milling scrap is sometimes digested with aircraft scrap. The mill scrap is weathered, and about 3 tons are required to make a ton of alumina. To produce 25 tons of alumina, 40 tons of mill scrap and 15 tons of aircraft scrap are required. About 0.5 ton of caustic soda and 0.6 ton coal for calcination are consumed per ton of alumina produced. Experimental work had indicated that 60 percent of the aluminum left in the residue can be extracted by treatment in autoclaves with caustic solution under 3 to 4 kilograms per square centimeter pressure.

Two industrial concerns operated by the Light Metal Control Association, formerly a government control agency, specialize in production of ingot by remelting cuttings, turnings, drosses, and shavings from rolling mills and fabricators. These are Kanto Saisei Kyogyo, K.K., and Kwansai Saisei Kogyo, K.K. They operate five small plants employing reverberatory and kettle furnaces.

The monthly secondary aluminum metal production is estimated to be 900 metric tons. This production rate, all secondary metal by United States standards, is not expected to increase. Japanese speak of metal containing 97 plus percent aluminum as "virgin metal", even though it is all produced from secondary sources by the methods just described.

Aluminum scrap (mostly duralumin containing about 4.0 percent copper, 1.0 manganese, and 0.5 magnesium) was estimated at the first of 1946 at 80,000 to 100,000 tons by Light Metals Control Association and by trade associations, according to Economic and Scientific Section Report No. 9. Field reports were conflicting, but on balance they are believed to be a fairly good estimate. From 1.25 to 3 tons of scrap of various grades is required to produce a ton of metal; therefore, some 50,000 to 60,000 tons of metal may possibly be recovered from scrap. This secondary metal must be remelted with high-grade to obtain purities satisfactory for most industrial uses. As of mid-November 1946, the Smelting Section of the Light Metal Council estimated the stocks of virgin metal in Japan to be about 1,500 tons.

## COSTS AND ECONOMICS

All Japanese aluminum has been consumed in domestic industry, as Japan has never exported the metal. The relation of the cost of production to selling price in yen, since the country reached large-scale production, has long been such that the margin of profit for the three principal producers was large - 30 to 50 percent of the sales prices. The economics of the Japanese aluminum industry are difficult to assess in terms of United States currency and conditions. The foreign-exchange value of the yen has been depreciating for many years. Legal exchange rate for United States currency was 23.4 cents per yen. It had declined to 2 cents in 1947, the rate fixed by Supreme Commander for the Allied Powers, SCAP, and the commodity value of yen is at present much below the legal exchange rate.

The long-sustained, artificially high prices of aluminum on the world markets, declining exchange value of the yen, and import duty equivalent to about 3 cents a pound for ingot and twice that for semifinished products, all have contributed to make domestic production of aluminum profitable. During the last few years of World War II and since, the impression has been widespread that the entire industry was born of war, was inefficient, economically unsound, and survived only on account of government subsidies, protective tariffs, and monopolistic practices. This is true only in the sense that they are true of the United States, Canada, and Germany, which also successfully developed great aluminum industries during the last 10 to 15 years while Japan was developing hers.

It has been mentioned that bauxite, fluorspar, and, indirectly, salt and other raw materials making up most of the cost of supplies must be imported into Japan. Even so, the average cost of imported raw materials amounted to only 3 percent of the value of the metal when sold in the form of utensils,

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4.5 percent of the value of fabricated aluminum, and 5 percent of the raw aluminum from 1937 through 1941.[7] Operating costs, including operating overhead, but before capital charges such as interest, amortization, and taxes are distributed to prime costs, supplies, labor, power, and overhead are about as follows for one of the largest Japanese aluminum producers: Repair and operating supplies, 55.5 percent of the total direct operating cost; labor, 10.1 percent; power, 29.5 percent; and miscellaneous direct operating overhead, 4.9 percent. The direct production costs for aluminum metal ranged between 1,054 yen and 1,916 yen per ton from 1939 through 1944. (Costs based upon the production of 2 tons alumina per ton of aluminum).

## GENERAL INFORMATION ON INDUSTRIAL ALUMINA AND ALUMINUM PLANTS

### Koriyama Plant of the Tohoku Shinko Aluminum Company, Ltd.

This plant is situated at No. 15, Miyata, Koriyama City, Fukushima Prefecture. It had a rated capacity of 4,000 metric tons of aluminum per year. Electrolysis of aluminum began July 13, 1939. The plant was damaged by floods on July 23, 1941, and by air raids on April 12, 1945. In July 1944, there was an acute shortage of oil, and the company substituted alumina trihydrate for alumina as feed to the cells, thus eliminating one process, the calcining of the hydrate to alumina in an oil-fired rotary kiln.

The plant comprised power substation; mercury arc-rectifier and transformer installation; two steel frame buildings, each housing two lines of twenty-six 18,000-ampere, open-type, block-electrode, electrolytic cells; two small remelt furnaces; and the usual laboratories, offices, and service shops. Most of the buildings, except those covering the pot lines, were wooden structures and were destroyed or heavily damaged by air raids. This stopped production completely, and operations were never resumed.

Virtually all of the electrical equipment except the electrolytic cells has been removed for use in production of ammonium sulfate fertilizer at Akita in Akita Prefecture. Nothing remaining at the Koriyama works is of material value for aluminum production. Some scrap metals, mostly iron and structural-steel framework and copper bus bars, were being reclaimed. Most of the latter appeared still to be in place.

### Kitakata Plant - Operated by the Showa Denko Co., Ltd.

The Kitakata aluminum plant is at No. 7840, Nagauchi, Kitakata Machi, Yama-Gun Fukushima Prefecture. This site was selected because of the many hydroelectric power stations in the Aizu district. In April 1939, 547,732 square meters of land was purchased, and on August 26, 1940, a plant for producing 9,000 metric tons of aluminum per year was started. The plant construction was finished on December 15, 1943. A second unit of the same capacity was started in October 1943 but was never finished owing to the shortage of materials.

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[7] Tiedeman H., The Aluminum Industry of Japan: Economic and Scientific Section of SCAP, Tokyo, Rept. 9, p. III. This is an exhaustive analysis of costs and prices to which the reader is referred.

The company bought the patent right of the Soederberg electrode system from Mitsui Bussan, K.K., which was the agency in Japan for Det Norsk Aktieselskeb for Electrokemisk Industri, Oslo, Norway. The settlement price was 1,317,000 yen.

This plant is a small, simple, but well-designed, efficient works, which consisted of substation containing four single-phase, 12,000-kilovolt-ampere transformers; twelve 3,100-kilowatt, mercury-arc rectifiers; four pot lines, each containing twenty-seven 40,000-ampere Soederberg cells; anode-paste plant; warehouses; laboratories; shops; offices; and several other service buildings.

Kitakata processed alumina from the Bayer plants of Showa Denko's at Yokohama and Omachi, Nippon Soda's Takaoka works, Nippon Keikinzoku, K.K.'s, Shimizu works, Tohoku Shinto, K.K.'s, and Nippon Aluminum, K.K.'s, Kurosaki plant and dry alumina (electric fusion process) from Showa Denko's plants at Toyama and Kanose. Some aluminum hydroxide was supplied by Showa Denko's plant at Yokohama.

The maximum production was reached on May 14, 1944, when 68 cells out of the 108 were in operation. This rate of production continued until January 1945, when the lack of alumina gradually cut production at the end of World War II to 24 operating cells. The total wartime production to July 1945 was 5,992 metric tons.

A feature of the Kitakata plant is its exceptionally high-capacity Soederberg, 40,000-ampere cells, the largest in the Japanese Home Islands. In April 1945, with alumina of rather poor quality, these cells made an average yield of 267 kilograms aluminum per day, consumed 20,927 kilowatt hours per metric ton of 99.5 plus percent metal, and attained an average current efficiency of nearly 90 percent operating at 36,886 amperes. In September 1946 the condition of the plant was excellent. Electrical equipment and pot lines appeared to be in condition to operate with a minimum of repair. Eighteen cells were in operation, and 619 employees were on the payrolls.

The building of an experimental plant for production of calcium nitrate was started soon after the end of hostilities. The plant was said to be producing about 1 ton per day and intended to expand to 100 tons per day if peacetime utilization of some of the existing plant machinery, particularly the electrical equipment, was authorized. The process in use is an obsolete, uneconomical one based upon the use of the German Schoenherr-type direct-arc furnace for the synthesis of nitrous oxide, which after further oxidation is absorbed in milk of lime to produce calcium nitrate. The first calcium nitrate fertilizer was produced from the pilot plant in October 1946.

### Niigata Plant - Operated by the Nippon Keikinzoku, K.K.

This plant is at No. 938, Dekishima, Niigata City, Niigata Prefecture, near the mouth of the Shinano River, and had a rated yearly capacity of 18,000 metric tons of aluminum. The maximum production of 18,477 metric tons of aluminum was attained in the calendar year 1943.

The Niigata plant was designed in the autumn of 1939 and production operations started January 27, 1941. In July 1944 the supply of Bayer alumina decreased, and aluminum dross was used as a substitute. In November 1943, this company was ordered by the government authorities to expand the plant to 27,000 metric tons aluminum annually. Owing to the shortages of necessary materials, such as steel, cast-iron, etc., only two wooden buildings were completed.

The plant follows closely the same general layout and good design of the same company's Kambara works. Materials can be delivered to the plant from ocean-going vessels, by freighters, or by rail. Power is transmitted at 154 kilovolts from Nippon Hassoden, K.K.'s hydroelectric generating system, to the plant's substation. Direct current is supplied by 18 arc rectifiers of 4,500 kilowatts capacity each. Two electrolysis plants each contain 6 pot lines of 22 cells each, all 132 cells connected in series. These cells are the enclosed, 32,000-ampere, Soederberg design. The works include cryolite and anode paste plants, the usual service shops, offices, laboratories, and storages for materials, with ample mechanical handling facilities. In addition, schools, a shrine, playgrounds, vegetable gardens, workers' residences, club, and staff apartments were provided.

The normal cost of power was 1.35 sen per kilowatt-hour, and the power consumption per ton of metal was the lowest in Japan. Technical operations were of high standard. Ceilings were placed on basic raw materials by the Light Metals Controlling Association. These, together with actual consumption, are shown in table 17.

TABLE 17. - Comparison of actual consumption of raw materials with allowable or restricted consumption

| | Alumina, kilograms | Electrode paste, kilograms | Cryolite, kilograms | Actual power consumption, kw.-hr. per ton Al |
|---|---|---|---|---|
| Maximum allowable consumption ... | 2,050 | 726 | 112 | 25,000 |
| Actual plant consumption: | | | | |
| October 1943 .................. | 2,110 | 662 | 103 | 21,972 |
| November 1943 .................. | 2,055 | 633 | 112 | 21,400 |
| December 1943 .................. | 2,075 | 653 | 112 | 20,394 |
| January 1944 .................. | 2,055 | 646 | 103 | 20,083 |
| February 1944 .................. | 2,002 | 633 | 93 | 19,594 |
| March 1944 .................. | 1,906 | 632 | 85 | 19,528 |

In 1946, the plant was found to be clean, in first-class physical condition, and had suffered no damage from air raids. Eight rectifiers were supplying current to 132 cells, only 20 of which were in production. Both scrap and dross were being treated. In all, 773 employees were on the payroll. The company proposed to convert much of the plant's equipment to the production of ammonium sulfate (up to 200,000 metric tons per year) and to making salt (at a rate of 12,000 metric tons annually). Niigata Prefecture is the largest rice-producing district in Japan, and no ammonium sulfate plant is situated therein.

## Sumitomo's Niihama Plant, Kikumoto Branch Factory

This plant is at Niihama, Ehime Prefecture, and is managed by Nissin Chemical Co., Ltd. The alumina section had a rated annual capacity of 54,000 metric tons. The alumina-calcining plant was 70 percent bombed out. The aluminum reduction plant had a rated aluminum capacity of 25,000 metric tons annually. A maximum production of 19,000 metric tons of metal was attained in 1944.

In January 1933, the experimental manufacture of alumina from Korean alunite was started in the Niihama plant of the Sumitomo Fertilizer Works, Ltd. In January 1936 the first alumina plant was erected. The sulfuric acid process for alunite was used. Owing to operational difficulties in the treatment of alunite and the possibilities of importing bauxite ore, the company changed to the Bayer process in 1938. The second plant, or first Bayer plant, started production of alumina in March 1940, and the third plant, or second Bayer plant, was put into production in November 1942. In 1944 the imports of bauxite ore were virtually cut off, and the company was compelled to reconvert the equipment to that suitable for treating aluminous shale from North China and Manchuria.

The Sumitomo Aluminum Reduction Co., Ltd., was established in June 1934. The construction work of the reduction plant, with an annual capacity of 1,500 metric tons, was started in January 1935, and production of aluminum began in March 1936. A second reduction plant was put into production in March 1940, and a third reduction plant in August 1941. The third reduction plant was severely bombed and destroyed by air raids in July 1945.

Sumitomo's light-metal works enjoyed the advantages of marine transport and direct mechanical handling of raw materials from steamer to plant bins. Coal was supplied from Kyushu, a short water haul. Complete integration of alumina, reduction facilities, and electrode plant on one plant site was an important factor in obtaining low costs. A further important advantage, especially for peacetime operation, is the plant's direct connection with the Nissin Chemical Co., Ltd.'s, extensive works, which produce coke, caustic, and other materials used in the aluminum industry. In addition to the aluminum and chemical works, Sumitomo has concentrated other facilities on Shikoku at Niihama, such as its Shikoku Machine Works, Seika Mining Co., power, townsite, and others. Sumitomo interests have extensive facilities at Nagoya and Osaka for production of light-metal shapes, sheets, rods, tube, and foil. Raffinal (refined) aluminum, a metal of extreme purity, is produced in Japan only by Sumitomo. Hydroelectric power at times must be supplemented by more expensive thermal power. Seasonal and off-peak operation feasible in peacetime, however, might offset this. At maximum production, the light-metal works required 70,000 kilowatts of power. On balance, however, Sumitomo's Niihama light-metal works is one of the most able to survive.

Plants not damaged by air raids were in better condition than some others visited. Dr. Yamazaki, managing director of Nissin Chemical Co., Ltd., stressed the company's interest in increasing its production of aluminum directly from scrap by the raffinal method, which employs a three-layer, inverted-type cell to produce high-grade metal. It is capable of making metal of exceptional purity, 99.95 percent aluminum, and even some containing more than 99.99 percent from mixtures of duralumin scrap and ingot metal.

The reduction works, of conventional type, consisted of three cell-sections; No. 1 section contained 90 block-electrode cells of 15,000 amperes; No. 2 had 160 Soederberg-electrode cells of 36,000 amperes; and No. 3 158 Soederberg cells of 30,000 amperes.

Since hostilities ceased, the plant is used to produce aluminum from scrap, sodium chloride, graphite electrodes, and calcium carbide.

### Shimizu Plant - Operated by the Keikinzoku, K.K.

This plant is at No. 4025 Miho, Shimizu, Shizuoka Prefecture. It was a Bayer-process plant with a rated capacity, in metric tons per year, of 100,000 alumina, 3,600 cryolite, and 1,100 tons aluminum fluoride. The plant's maximum annual production of 101,320 metric tons alumina was attained in 1943.

Construction of the plant began in August 1939, production of alumina got underway in September 1941, and full operations were attained in 1943. The plant started on imported bauxite but had to resort to the treatment of domestic raw materials such as alunite, aluminous shale, and clinker, treating them by methods similar to Bayer's. After the termination of World War II, the plant shut down for several months. On February 12, 1946, the production of alumina from dismantled aircraft and metal scrap was started. Part of the plant was converted to the manufacture of potash fertilizer, sodium chloride, and fire brick.

The alumina produced at Shimizu was hauled by trucks to its reduction works at Kambara, a distance of 15 kilometers. It is believed that these two plants constitute the best complete alumina and aluminum facilities in Japan, from technical and perhaps economic standpoints. The two plants are connected by both rail and water.

### Kambara Plant - Operated by Nippon Keikinzoku, K.K.

This plant, at No. 161 Kambara-Cho, Thara Province, Shizuoka Prefecture, had a designed annual capacity of 36,000 metric tons. The company was established in March 1939, and aluminum production began in October 1940. Maximum production of 31,057 metric tons of aluminum was attained in 1943. Operations at the plant were suspended on July 25, 1945, owing to air raids.

Soederberg cells were used, for which a royalty of 2,100,000 yen was paid to the Mitsui Bussan Co., Ltd. Mr. K. Yasuda, plant general manager, developed a special method of lowering the anode during the interruption of electric-current supply, "the anode dipping method," or "the temporary stopping method of furnace operation." It is claimed that by this method an electrolysis furnace can be started again without sacrificing the purity of the aluminum metal.

The most perplexing technical problems encountered were the treatment of powdered aluminous shale as a partial substitute for Bayer alumina. The principal difficulties were in oxidation of anode carbon, irregular consumption of anodes, greater consumption of other auxiliary materials, including electric energy, and faster deterioration of furnaces.

### Toyama Plant - Operated by Showa Denko, K.K.

This plant, at Toyama, Toyama Prefecture, was among the earliest Japanese alumina-aluminum concerns to get into production. Beginning in 1935 with an alumina production of 1,000 metric tons, it attained a maximum production of 11,165 metric tons in 1940. The aluminum production started in 1935 and reached a maximum of 5,770 metric tons in 1943. The aggregate production of alumina and aluminum from 1935 to June 1945, inclusive, was, respectively, 72,900 and 38,579 metric tons. About 20,000 metric tons of alumina were produced by direct reduction of high-iron bauxites and aluminous shale in an electric furnace. It was reported that the over-all cost of production was 485 yen per ton of alumina, compared to 650 yen for Bayer alumina. This electrothermic process, known in Japan as the Nichiman or "electric-fusion" method for producing "dry alumina," has some merit from the standpoint of low capital investment required, low cost, simplicity, and adaptability to special conditions such as may exist in postwar Japan. It must have several defects remedied by further development before the process can be considered serious competition to the Bayer method.

The availability of electric power varies with the season of the year in Japan. The percentages of power available for this plant's operation, by months, are as follows:

| | Percent | | Percent | | Percent |
|---|---|---|---|---|---|
| January ..... | 30 | May ......... | 100 | September ... | 100 |
| February .... | 25 | June ........ | 100 | October ..... | 100 |
| March ....... | 50 | July ........ | 85 | November .... | 75 |
| April ....... | 100 | August ...... | 80 | December .... | 50 |

In 1946, it was producing in metric tons per month, alumina, 200 to 300; ferro-silicon, 200 to 300; carbide, 10; and sodium chloride, 45. Some pig iron was also produced.

It was difficult to obtain anthracite from French Indo-China, as well as hard bauxite ores from both Greece and French Indo-China, and, therefore, the substitutes which were used resulted in a poor quality alumina. Also this plant suffered loss of production and quality of product by operating under controlled economy.

### Takaoka Plant - Operated by Nippon Soda Co., Ltd.

This plant, at No. 420, Mukaino-Machi, Takaoka City, Toyama Prefecture, is an integrated plant having a rated annual capacity, in metric tons of alumina, 20,000; aluminum, 10,000; block carbon anode, 3,500; paste carbon anode, 4,500; and cryolite, 800. It also has facilities for production of important tonnages of many heavy chemicals and organic and pharmaceutical compounds.

The Nippon Soda Co., Ltd., entered the aluminum industry in 1937 and rapidly expanded its capacity to 20,000 metric tons Bayer-process alumina and 10,000 metric tons aluminum annually. Aluminum became the company's most important wartime product. Maximum production of 22,327 metric tons alumina and 10,795 metric tons aluminum per year was attained in 1944. Production ceased at the end of the war, and the company returned to the production of heavy chemicals, salt, and pharmaceuticals. Chlorine and caustic are produced in mercury-type electrolytic cells similar to the German mercury cell. This plant was not damaged by air raids.

The Bayer process was used for production of alumina, and equipment included the usual ore- and materials-handling equipment, kilns, grinding mills, autoclaves, thickeners, filters, tankage, evaporators, gas producers, boilers, and auxiliary equipment required to operate the major equipment. Pot lines in the aluminum plant included 150 block-electrode type 20,000-ampere cells, and 100 Soederberg-type 30,000-ampere cells. Carbon plant included equipment for production of paste and solid anodes to aggregate 8,000 tons yearly.

Power consumption at best was 26-27 kilowatt-hours per kilogram of refined aluminum, or about 12 kilowatt-hours per pound, a figure comparable to United States practice. Annual averages are about 32 to 33 kilowatt-hours per kilogram.

Cost reported by Light Metal Control Association was 650 yen per metric ton of alumina and 2,800 yen for aluminum with power at 1.4 sen per kilowatt-hour for 1940-41. This apparently includes heavy charges for general expenses and return of capital. Direct operating costs were lower.

Weighted average of direct operating costs, according to company records, for 1937-41 were 359 yen per metric ton alumina and 1,900 yen for metal. These costs were based upon the production of 40,816 tons of alumina and 18,480 tons of aluminum.

Nippon Soda, K.K., fourth-ranking producer in Japanese Home Islands, made a good record for production and costs of operation of its alumina-aluminum works despite handicaps of older equipment and perhaps less efficient layout of plants, higher power cost, and less favorable conditions for transport and handling of large tonnages of materials than enjoyed by Nippon Keikinzoku, K.K., Showa Denko, K.K., and Sumitomo Aluminum Seiren, K.K., ranking, respectively, first, second, and third in capacity. Advantages included assembly of all facilities required in the production of alumina and metal in one plant. Long experience in electrochemical work and integration of operations with related manufactures of the company's many other products also were advantageous.

This plant did not operate smoothly during any extended period of the war. Difficulty was encountered in getting a clear sodium aluminate solution when treating Palau bauxite ore, and considerable confusion took place in the plant when shale, dross, and aluminum scrap were processed. The shortage of fuel oil for the calcining kilns forced the company to use producer gas, and good-quality coal for gas production was difficult to obtain.

## Omuta Plant - Operated by Mitsui Keikinzoku, K.K.

This plant is at No. 2081 Tosen Omuta City, Fukuoka Prefecture. It had a rated capacity of 24,000 metric tons of alumina per year.

The plant was built to supply the Mitsui-owned 12,000 metric tons capacity Yoshi reduction works near Shingishu in Korea north of 38° parallel. It went into production and in 1943 made about 14,000 metric tons alumina from Bintan and Palau bauxites. Late in 1944, when bauxite could not be obtained, an effort was made to use clinker and the lime-soda process from North China clay. Production fell, and cost rose from 450 yen per ton, using Bayer process or bauxite, to 5,000 yen per ton on clinker. Total production for 1944 was 11,180 tons. When imported clay could not be obtained, owing to Japanese loss of shipping, an effort was made to again convert the plant to operate on local clay containing 30 to 35 percent available aluminum oxide, 30 percent silicon oxide, and 10 to 15 percent iron. The plant didn't operate on this material, owing to closing down at the end of World War II. The greatest difficulty in operation of the lime-soda process on clay was mechanical handling of stiff clay muds in thickeners, but chemical and process difficulties also were encountered.

Owing to the almost continuous changes made in 1944 and 1945 and the actual dismantling of parts preparatory to proposed shipment to Korea, some sections of the plant are in poor condition.

## Kurosaki Plant - Operated by Nippon Aluminum Co., Ltd.

This plant is at No. 2577 Aza Higashiwari, Oaza Kumade Yahatu City, Fukuoka Prefecture.

Nippon Aluminum, K.K.'s, Kurosaki aluminum works, with paid-up capitalization of 60,000,000 yen, could produce 24,000 tons Bayer-process alumina annually. With some revamping, company engineers claim it could produce up to 36,000 tons, or 20,000 tons from shale by the lime-soda-sinter process. The plant is economically situated with respect to fuel and chemical supplies but has no reduction works of its own. It was designed to supply Mitsubishi-owned plants in Formosa. These plants, owing to the complete destruction of 9,000 tons annual aluminum capacity, have about 12,000 tons excess alumina capacity.

The Kurosaki works, as it stands, is one of the best in Japan from the standpoints of design and economic location with respect to fuel, chemicals, and transportation. These factors make it better adapted than most plants for reconversion to production of other products.

Mitsubishi's Nippon Aluminum, K.K.'s, alumina plant at Kurosaki, like Mitsui's Omuta plant, was built for processing Bintan bauxite into alumina, the latter to be reduced to metal in plants outside of the Home Islands. The Kurosaki works, equipped as a combination process Bayer lime-soda plant (aggregate nominal capacity of 24,000 metric tons annually), supplied alumina to company-owned reduction works at Takao and Karenko, cities in Formosa.

Kurosaki also supplied these works with up to 7,000 tons of carbon anode annually. Anode material production capacity of 12,000 tons annually is claimed by the management. Kurosaki went into operation early in 1941 to produce 10,460 tons, 16,475 in 1942, 17,958 in 1943, and 16,543 in 1944, 15,414 of which was produced from aluminous shale by the lime-soda process. The works, claimed to be the first Bayer plant in Japan, made a good record for production and costs, well-advised technically, carefully engineered, well-constructed, and apparently well-managed. When part of the plant (14,000 tons per year capacity) was converted to the lime-soda process to treat imported aluminous shale, difficulties (mostly mechanical) were encountered, production decreased, and costs soared. Near the end of World War II, when aluminous shale could not be imported, some unsuccessful laboratory work was done on domestic shale from Yame district (Fukuoka Prefecture) by the lime-soda process. Difficult operating and mechanical conditions prevailing near the close of operations of the lime-soda process together with limited experience probably are largely responsible for its failure.

In general, the plant is a good one, well-situated with respect to coal and marine transportation for raw materials and finished products. The company-owned Chikuho coal mines are near. Gaseous fuel for furnacing was obtained from Mitsubishi Chemical Industry's works adjoining the alumina works. Liquid caustic soda was delivered by barges from the chemical company's Makiyama factory in Yahata City, a few miles away. As the plant was built to produce only alumina (and that for export), it has neither reduction plant for making aluminum nor rolling or fabricating facilities. It is situated, however, in a great manufacturing area and is closely integrated with Mitsubishi chemical works nearby. A surprisingly heavy payroll of about 250 workmen was being carried at the time of the visit, and the technical staff (33 men) appeared alert, well-informed, and generally competent. As the plant stands, it has capacity and equipment to produce 10,000 tons alumina annually by the Bayer process on bauxite and 14,000 tons capacity for treating aluminous shale by the lime-soda process.

## Tonda Plant - Operated by Toyo Soda Manufacturing Co., Ltd.

This plant is at 4560 Tonda, Tokuyama City, Yamaguchi Prefecture, with a rated capacity of lime-soda-sinter alumina of 14,000 metric tons per year. The plant started production of alumina trihydrate in May 1944 and suspended in August 1945. The highest actual production rate was in June 1945, when the equivalent of 9,500 metric tons of aluminum oxide was made. The plant also had a rated capacity, in metric tons per year, for salt, 7,200; soda ash, 250,000; caustic soda, 4,000; hydrochloric acid, 1,600; and bromine, 720.

Toyo Soda's alumina trihydrate plant was strictly a war effort to provide for alumina production from aluminous shale by the lime-soda-sinter process, using existing equipment belonging to the Solvay soda plant. As an alumina unit it is incomplete, uneconomical, and poorly placed.

Toyo Soda, K.K., is primarily a chemical concern producing the heavy chemicals listed above. Manufacture of soda ash and caustic were discontinued in 1944, and the facilities were used for production of alumina trihydrate (not alumina). Addition of tankage, filters and materials-handling equipment were made to accommodate the lime-soda-sinter process. The plant feed was aluminous shale clinker containing about 33 percent alumina produced by sintering the shale with lime and soda in rotary kilns at cement plants. Asano Cement Co. at Itozaki and Onoda Cement Co. at Onoda and Yahata supplied the clinker until shipment of shale was cut off by allied nations. Alumina trihydrate production at Tonda works, therefore, was discontinued.

In the lime-soda-clinker process, as operated at Tonda, the clinker was treated with hot caustic stock solution and steam to extract soluble alumina. The pulp was washed by countercurrent decantation, and the "red-mud" underflow of the last thickener was discarded. Pregnant alumina solution was "desilicated" with milk of lime at 95° C. and thickened. Purified solution (thickener overflow) was treated with carbon dioxide in carbonating towers in the soda-ash plant. Resulting alumina trihydrate (white slurry) was thickened, filtered, and sacked for shipment to other works for reduction or use in the manufacture of cryolite. Part of the recovered solution was evaporated and centrifuged to recover soda ash; the other part was mixed with "mud" (sodium aluminum silicate resulting from the desilication step) in recovering and causticizing tanks at 95° C. The pulp was washed by countercurrent decantation, and the "white mud" containing some alumina and soda was discarded. Wash solution was returned to the extraction tanks at the head of the plant, where it was used as cyclic stock or dissolving solution to extract alumina from clinker. Mechanical and process difficulties were encountered in the separation of pregnant solution from red mud, and losses were high. By the time these difficulties were overcome, the difficulties of obtaining clinker, fuel, and supplies became so great that the plant suspended operation. The entire operation resulted in about 3,750 tons of alumina equivalent.

Some work is being done towards restoring the plant to its original use. Most major equipment is in workable condition or could be reconditioned at reasonable cost. Pumps, motors, and other auxiliary equipment appear to be in good shape. Buildings housing the alumina plant are greatly in need of repairs but were not bomb-damaged. Most of the thickener superstructures are in good condition, as are most of the evaporators.

### Shikama Plant - Operated by Osada Kagaku Kogyo, K.K.

This plant, at Shikama, Hyogo Prefecture, produced 7,628 metric tons of alumina from alunite by two hydrometallurgical processes. Sulfuric acid was used as the solvent from 1935 to 1938, and 1,900 metric tons of alumina was produced. Early in 1938, the company changed to caustic soda as the solvent and produced 5,700 metric tons of alumina. The alumina was treated by Showa Denko, K.K., and Sumitomo's Niihama reduction plants. The raw materials required to produce 1 metric ton of aluminum are shown in table 18. The weights of products and volumes of solutions per 1 metric ton of alumina produced, together with their assays, are shown in table 19 for the acid process and in table 20 for the alkaline method.

TABLE 18. - Raw materials, in kilograms, required to produce 1 metric ton of aluminum

| Material | Kilograms per ton of aluminum | Analyses, percent | | |
|---|---|---|---|---|
| | | Si | Fe | Ca |
| Alumina ......... | 2,000 | 0.971 | 0.543 | 0.542 |
| Electrode ....... | 830 | 0.146 | ND | ND |
| Cryolite ........ | 200 | 0.280 | 0.070 | ND |
| Al fluoride ..... | 220 | 0.028 | 0.010 | ND |

ND = No data available.

The acid process for recovering alumina from alunite was said to have won the prize of "des Arts et des Techniques" at the 1937 Exposition Internationale in Paris. Technical difficulties, especially in the recovery of sulfuric acid, were encountered in industrial-scale operations, so the process was abandoned after 2 years' operation in favor of the use of caustic soda as solvent. Figure 13 is a flow sheet of the acid process showing approximate quantities required per ton of alumina, and table 10 contains analyses of the 10 products numbered on the flow sheet. Alumina produced by the process was reduced to metal at Sumitomo Aluminum Seiren, K.K.'s, Niihama works in Ehime Prefecture. Ingots contained 99.7 percent aluminum.

Most of Asada Kagaku's production of alumina resulted from the treatment of potash alunite from Gyokumaizan Koan, Asada Kagaku Kogyo, K.K., in Zenranan Prefecture, Korea. This ore contained about 25 percent alumina, as shown in table 10. During all of 1944, and to September 1945, a soda alunite supplied by Nishina Kozan Sansen Kogyo, K.K., Nishina, Shizuoka Prefecture, was treated by the alkali process with caustic soda as solvent. A typical analysis of the soda alunite is shown in table 10.

The alunite was first ground to pass a 65-mesh sieve, which was sufficient to obtain extraction of the alumina without undue dissolution of silica. The alunite was then digested with caustic alkali solution at about 70° C. for 2 hours. The solution contained the chemicals in ratios as shown, gravimetrically:

Six sodium aluminate ($NaAlO_2$)
Three sodium sulfate ($Na_2SO_4$)
One potassium sulfate ($K_2SO_4$)

The aluminate liquor was pumped to the precipitating tanks, were it was mixed with a "seed" charge of alumina trihydrate from a previous cycle. The mixture had to be agitated continually and gradually cooled under conditions that permitted the formation of coarsely crystalline alumina trihydrate at a temperature between 30° and 35° C.

The precipitated alumina trihydrate was finally filtered off from the solution, washed, and sent to the calciner, a 242-foot tunnel kiln. There the trihydrate was heated to a temperature substantially above 1,100° C. to convert it into anhydrous alumina suitable for the electrolytic reduction process. The solution (mother liquor) still contained sodium and potassium sulfates and undecomposed alumina; it was concentrated by evaporation, and sodium sulfate was separated by crystallization.

TABLE 19. - Amounts and analyses of products and solutions used per metric ton of alumina by the alunite acid process

| Composition | Potash-alunite (6.58 MT), percent | Calcined alunite (5.63 MT), percent | Potash alum (4.18 MT), percent | Potash alum (13.35 MT), percent | Potassium sulfate sol. (18.64 $M^3$), G/L | Alumina (1.00 MT), percent | Residue (4.98 MT), percent |
|---|---|---|---|---|---|---|---|
| $H_2O$ ............... | 8.95 | 3.48 | 33.80 | ND | ND | 0.120 | 43.10 |
| $SiO_2$ ............... | 34.99 | 38.80 | 0.024 | 0.005 | 0.80 | 0.100 | 42.90 |
| $Fe_2O_3$ ............... | 2.71 | 3.01 | 0.004 | 0.001 | 0.10 | 0.028 | 3.13 |
| CaO ............... | 0.25 | 0.28 | Trace | Trace | Trace | 0.003 | 0.21 |
| $Al_2O_3$ ............... | 24.79 | 27.50 | 25.35 | | 15.55 | 99.650 | 5.71 |
| $K_2O$ ............... | 5.78 | 5.97 | 7.69 | | 48.25 | 0.078 | 1.02 |
| $Na_2O$ ............... | 0.88 | 0.88 | 0.097 | | Trace | | 0.16 |
| $SO_3$............... | 24.09 | 20.68 | 33.80 | | 100.50 | 0.025 | 3.71 |

Note: Some of the analyses were average figures, and totals do not add to 100 percent.

There were 2.50 cubic meters of soda alum solution that contained 279 grams per liter $Na_2SO_4.Al_2(SO_4)_3.24H_2O$. The 0.27 metric ton of potassium sulfate was 98 percent pure. There were 1.17 metric tons of concentrate sulfuric acid.

$M^3$ = Cubic meters
MT = Metric tons
G/L = Grams per liter
ND = No data available

TABLE 20. - Amounts and analyses of products and solutions used per metric ton of alumina by the alunite alkaline process

| Composition | Potash-alunite 5.71 MT, percent | Aluminate solution 28.0 $M^3$, G/L | Mother liquor 26.0 $M^3$, G/L | Mother liquor ($Na_2SO_4$) 6.4 M3, G/L | Washing solution 1.16 $M^3$, G/L | Alumina, percent | Glaserite, percent | Residue, percent |
|---|---|---|---|---|---|---|---|---|
| $H_2O$ ............. | 8.95 | - | - | - | - | - | 3.75 | 41.80 |
| $SiO_2$ ............ | 34.99 | 1.07 | 1.08 | 1.95 | 0.82 | 0.104 | 0.05 | 44.00 |
| $Fe_2O_3$ ........... | 2.71 | 0.01 | 0.01 | 0.01 | 0.01 | 0.039 | 0.02 | 3.63 |
| CaO ............. | 0.25 | - | - | - | - | 0.040 | 2.90 | 0.31 |
| $Al_2O_3$ ........... | 24.79 | 77.00 | 39.50 | 73.25 | 43.08 | 97.450 | - | 5.52 |
| $K_2O$ ............. | 5.78 | - | - | - | - | 0.066 | - | 0.51 |
| $Na_2O$ ............ | 0.88 | 86.00 | 85.80 | 164.80 | 94.66 | 0.810 | - | 1.64 |
| $SO_3$ ............. | 24.09 | - | - | - | - | 0.146 | - | 2.34 |
| $K_2SO_4$ ........... | - | 51.80 | 53.50 | 94.25 | 55.95 | - | 46.25 | - |
| $Na_2SO_4$ .......... | - | 168.40 | 173.70 | 135.70 | 173.60 | - | 47.20 | - |
| $Na_2CO_3$ .......... | - | 9.60 | 12.30 | 6.88 | 12.31 | - | - | - |

$M^3$ = Cubic meters.
MT = Metric tons.
G/L = Grams per liter.

After sodium sulfate had separated, the liquor was cooled to room temperature, at which glaserite began to crystallize. The liquor, after the addition of more sodium hydroxide to bring it up to the required strength, was used for the digestion of a new charge of potash alunite.

The sodium sulfate was treated with dilute sulfuric acid and shipped to a glass factory. Caustic soda, which cost 302 yen per ton, was consumed at the rate of about 1.4 tons per ton of alumina.

Equipment included crushing and grinding machinery, six 18- by 18-foot leaching tanks, 76 Bayer tanks 12- by 16-foot, 11 filter presses, 5 drum-type vacuum filters, and a 242-foot tunnel kiln 8- by 13-foot cross section. Auxiliary equipment included coal-burning gas producers, evaporators, boilers, and packing machines.

Messrs. Asada and Nakashima, who developed and operated the alkali process at Shikama, believed that the process could be developed further from the technical standpoint but saw little hope for the process from the economic point of view, owing to the high cost and consumption of caustic soda, compared to the Bayer process based on bauxite.

### Hachinohe Plant - Operated by Nittoh Kagaku Kogyo, K.K.

This plant, at Hachinohe City, Aomori Prefecture, was a pilot plant that treated phosphate rock and had an annual capacity of 700 metric tons alumina. The plant began operations in 1940 and was severely bombed in July 1945. Maximum production of 492 metric tons was attained in the calendar year 1944.

The plant contained modern types of chemical processing equipment, including some of stainless steel. The flow sheet indicates the use of hammermill crushers, kiln dryers, ball mills, acid-resisting tanks, digesters, lead-lined acid-handling equipment, plate and frame filter presses, centrifuges, mixers, multiple-effect evaporators, Cottrell precipitators, and the usual auxiliary equipment for the handling and storage of materials.

The process and plant were designed to treat aluminous phosphate rock from deposits on North Diato Island. An effort was made, also, to process Fukubando clay containing about 70 percent halloysite, supplied by Kokusan Keigin, K.K., from the Kurosawajiri deposit in Iwate Prefecture. About 2,500 tons of clay was treated but proved expensive and extremely difficult mechanically. Failure of acid-proof equipment was said to be the greatest stumbling block.

The phosphate rock was described as an amorphous mixture of $P_2O_5m(Al_2O_3)$ and $Al_2O_3n(SiO_2)$ containing about 40 percent $Al_2O_3$ and 25 percent $P_2O_5$. Analyses of the rock and Fukubando clay are shown in table 21 together with intermediate and final products of the process as applied to the phosphatic material. Power and materials required to produce a ton of alumina from each ore are listed in table 22. Electric power was purchased from Tohoku Haiden, K.K., at 1.25 sen per kw.-hr. River water was pumped about 2 miles to the works, where it was filtered and softened to insure purity of products.

TABLE 21. - Analyses of ores and products, Hochinohe plant, Nittoh Kagaku Kogyo, K.K.'s alumina plant

| | Percent composition and specific gravity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Material | $H_2O$ | LOI | Sp. Gr. | $Al_2O_3$ | $Fe_2O_3$ | $NH_3$ | $P_2O_5$ | $SO_4$ | $SiO_2$ | CaO | Total $N_2$ | $SO_3$ |
| Phosphate rock (raw ore) ... | 31.7 | 19.6 | ND | 42.9 | 4.3 | ND | 26.8 | ND | 19.7 | 7.2 | ND | ND |
| Residue (filter cake) | 78.0 | ND | ND | 2.6 | Tr. | 1.7 | 0.2 | 11.3 | 4.1 | 2.3 | ND | ND |
| Crude alum ... | 4.2 | ND | ND | 11.1 | 0.1 | 3.8 | 0.4 | 40.7 | 0.04 | 0.07 | ND | ND |
| Refined alum.. | 2.5 | ND | ND | 11.5 | 0.02 | 3.7 | 0.12 | 41.5 | 0.03 | 0.03 | ND | ND |
| $Al(OH)_3$ ...... | ND | ND | ND | 14.8 | 0.03 | 4.9 | 0.08 | 8.5 | 0.05 | 0.01 | ND | ND |
| $Al_2O_3$ ........ | ND | 0.25 | 3.8 | 99.2 | 0.16 | ND | 0.16 | 0.06 | 0.16 | Tr. | ND | ND |
| Phosphate fertilizer .. | 15.0 | ND | ND | 2.0 | 1.0 | ND | 10.0 | ND | ND | ND | 20.0 | 5.2 |
| Ammonium sulfate ..... | 2.0 | ND | ND | ND | Tr. | ND | ND | ND | ND | ND | 20.7 | ND |
| Fukubando clay ........ | 56.0 | 16.0 | ND | 28.0 | 9.0 | ND | ND | ND | 55.0 | 8.0 | ND | ND |

ND = No data.
LOI = Loss on ignition.

TABLE 22. - Materials required to produce 1 metric ton of alumina from phosphate rock or Fukubando clay, Hochinohe plant, Nittoh Kagaku Kogyo, K.K.'s alumina plant

| Material, metric tons | From phosphate rock | From Fukubando clay |
|---|---|---|
| Ore ...................................... | 10.3 | 31.5 |
| Ammonia (100 percent $NH_3$) ................ | 2.4 | 1.0 |
| Sulfuric acid (80 percent $H_2SO_4$) ........ | 15.3 | 14.4 |
| Coal for roasting ....................... | 2.0 | 6.1 |
| Coal for steam .......................... | 3.8 | 4.2 |
| Electric power, kw.-hr. ................. | 1,700.0 | 3,500.0 |
| Petroleum fuel .......................... | 1.1 | 1.2 |
| Ammonium sulfate used ................... | 0 | 2.8 |
| Ammonium sulfate byproduct .............. | 3.0 | 3.2 |
| Water handled ........................... | 1,000.0 | 5,000.0 |

Dr. Yogaro Kato, who owned several alumina patents, received royalty from Nittoh Kagaku for use of the process. It consisted of four steps: (1) decomposition of the ore by sulfuric acid and crystallizing out ammonium alum; (2) purifying the alum by recrystallization; (3) conversion to alumina trihydrate by aqueous ammonia; and (4) calcination of hydrate to alumina.

## Yokohama Plant - Operated by Showa Denko, K.K.

The present plant was designed to produce 225 metric tons of alumina from bauxite by the Bayer process. A maximum production of 56,764 metric tons alumina was attained in 1943. At the close of the hostilities, the plant had an effective capacity of 21,000 metric tons alumina from bauxite and 7,200 metric tons from scrap. The plant offices were bombed by air raids on May 29, 1945, and most operating data were destroyed.

The original plant was constructed in June 1933, under the name Nihon Alumina Kogyo Sho Yokohama plant, to manufacture alumina and potassium-ammonium sulfate from Korean alunite. Production of cryolite was begun in 1934, and in 1935 graphite electrodes and caustic potash were produced. In 1937 a Bayer alumina plant was added for the production of alumina from bauxite ore. In November of the same year the company began the production of caustic soda. The Nihon Denki Kogyo, K.K., and Showa Hiryo, K.K., were combined in 1939 to form the Showa Denko, K.K. The Showa Sangyo, K.K., was annexed to the Showa Denko in 1943, and production of catalytic sulfuric acid was begun. The treatment of aluminum scrap and crude metal and also the processing of aluminous shale for the production of alumina got underway in 1944.

After hostilities ceased in 1945, this plant continued to produce alumina from scrap and also produced hydrochloric acid, bleaching powder, caustic soda, liquid chlorine, ammonium chloride, calcium chloride, graphite electrodes, sodium chloride and ferrous sulfate.

Various processes and raw materials were used in this plant since 1933. As Japan has no domestic bauxite resources, she began to treat Korean alunite by the ammonia soda process. In this process the ore is crushed, roasted, pulverized, and then heated with ammonia water in autoclaves to render the potassium soluble. After filtering off the soluble salts, the residue is treated with caustic soda solution to dissolve aluminous compounds as sodium aluminate. The pregnant liquor is treated with carbon dioxide gas to precipitate alumina trihydrate. The alumina trihydrate is calcined to alumina, and the sodium carbonate solution, after causticization with lime, is used for plant solution. The main difficulty in this process was in getting a uniform roast of the ore. The lack of uniformity in the roasting caused incomplete extraction of the sulfate radical in the subsequent treatment with ammonia. The treating of a high-sulfate radical residue with caustic caused a considerable loss of soda in the form of sodium sulfate.

The caustic-potash process was tried on pulverized, unroasted alunite ores. The ore was treated with caustic potash solution in autoclaves. The solution contained potassium sulfate and potassium aluminate. The sulfate was precipitated by crystallization, and the aluminate was treated by the Bayer method. In spite of the technical success, economically this process proved a failure principally on obtaining markets for the byproducts of crude and pure potassium sulfates.

From 1937 to 1945 a modification of the Bayer process was used. The uncalcined bauxite ore was pulverized in ball mills with 200-gram-per-liter caustic-soda solution, and the pulps were pumped into autoclaves for subsequent treatment by the Bayer process.

The Ministry of Munitions in October 1944 ordered the aluminum manufacturers to process aluminum scrap and crude metal. At this plant, these metals were put into decomposition tanks filled with caustic-soda solution, which came back from the alumina trihydrate precipitation. The sodium aluminate liquor is processed by the Bayer method.

The concentrated alkali process for aluminous shale was in the experimental stage at the end of the war. In this process, aluminous shale from North China was crushed and milled with caustic-soda solution of 450 grams per liter NaOH. The pulp was treated in autoclaves. The first step of the autoclave treatment was evaporation of the pulp to the concentration of 650 grams per liter NaOH. The pulp was further heated to 190° C., diluted, and discharged from the autoclaves. From this step, the treatment was the same as the Bayer process for bauxite ores.

Many perplexing problems were encountered at all plants when operating under wartime conditions, suffering shortages of materials and supplies, repairing damaged plants, equipment, etc. This plant mentioned one of particular interest. When production of alumina from scrap metal was begun, it was difficult to protect the plant from air raids, owing to the numerous explosions of the hydrogen gas evolved from the dissolution of metal in the caustic solutions.

### Omachi Plant - Operated by Showa Denko Co., Ltd.

This plant, situated at Omachi, Nagano Prefecture, had a rated annual capacity of aluminum of 18,000 metric tons. Virtually 100 percent of the alumina treated at this plant was produced at Showa Denko's, K.K., Yokohama plant. In 1943, the plant produced 21,363 metric tons of aluminum. Here were facilities for producing annually, in metric tons, 18,000 carbon electrodes, 2,500 artificial graphite electrodes, 4,800 silumin, 2,180 recovered cryolite, and 900 dry-process alumina. This dry-process alumina plant was converted after the war to the production of 300 metric tons per month calcium carbide.

It required 25,000 kilowatt hours of electric energy and, in metric tons, 2.1 alumina, 0.02 aluminum fluoride, 0.08 cryolite, 0.80 anode carbon, 0.05 cathode carbon and 0.08 recovered cryolite to produce 1 metric ton of aluminum. To produce 1 metric ton of silumin, it required 0.15 metric tons of heavy oil, or 1,000 kilowatt-hours electric energy. It also required, in metric tons, 0.883 aluminum (99.3 percent) and 0.132 metallic silicon (Fe, 0.58 percent, Al 0.22, percent, Ca 0.18, percent.).

### Toyama Plant - Operated by Kokusan Keigin Kogyo, K.K.

This plant, now under the name Nippon Kagaku Hiryo, K.K., is at No. 1870 Takanchi, Osawano-Machi, Kaminiikawa-gun, Toyama Prefecture. It had a rated capacity of 2,000 metric tons of aluminum from alumina annually and 1,700 crude aluminum from shale. The plant operated only a few months in 1944 and 1945 and produced 42 metric tons of aluminum from alumina and 295 metric tons from aluminous shale.

In 1937 the Japan Electric Power Co. decided to build an aluminum plant to consume the surplus electric power that it proposed to generate in a nearby district. The plant was not built until December 1943. A few units of the plant were put in operation on November 15, 1944. The stock of alumina was very low, and the feed to the cells was part alumina and part aluminous shale. From February 15, 1945, only the aluminous shale was used as raw material. After hostilities ceased, the plant manufactured aluminum castings from the low-grade metal they had produced.

### Iwate Plant - Operated by Kokusan Keigin Kogyo Co., Ltd.

This plant, situated at Waga-gun, Iwate Prefecture, had a rated annual capacity of 12,000 metric tons alumina. The maximum production was 236 tons in 1941.

In 1938 the plant began using the sulfuric-acid process on clay, which was replaced by the sulfurous acid process in 1943 because of the shortage of ammonia. The sulfur dioxide process did not get much beyond the experimental stage.

### Manshu Keikinzoku, K.K. Calcium-Aluminate Plant

This plant, operated by the Manchurian Light Metal Manufacturing Co., Ltd., was situated at Fushun, Manchuria. It had 200 electrolytic furnaces and a rated annual capacity of 10,000 metric tons. Soederberg 24,000-ampere cells were used. The company was founded in 1936, and the plant was completed in 1938. From 1941 to the end of hostilities, it succeeded economically in making aluminum of quite good quality from Manchurian aluminous shale by the calcium-aluminate process.

## LABOR

The Japanese metal industry was built up by technical students, who had gained considerable knowledge of processes from the literature of foreign countries. This was supplemented by the influx into Japan of foreign engineers, who aided in the design, construction, operation, and instructing the Japanese in the technical aspects of becoming skilled laborers.

At the outbreak of hostilities in 1941, very few foreign engineers were left in Japan. As the war progressed, Japanese skilled labor was more heavily drawn upon for the armed forces. The labor in general was replaced with forced Japanese labor supplemented by prisoners of war. As a result, the man hours required per unit of product produced gradually increased, and at the same time the quality of the skilled labor plus the treatment of inferior raw materials caused a lower-grade product to be produced. In many instances the finished products could not meet specifications and were rejected for certain specified jobs.

The relationship between labor and the companies is cordial. In pre-war time, the Japanese industrial companies considered the welfare of labor their responsibility, and in many instances provided living quarters, recreation facilities, shrines, hospitals, etc. In some areas the workers were even allotted space for their own little vegetable gardens.

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